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Research article

Drying kinetics and mathematical modeling of coconut meat slices: Insight into pretreatment and drying synergic effect

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A R T I C L E I N F O

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A B S T R A C T

Coconut consumption provides nutritional and health benefits to humans. Yet, poor postharvest and preservation methods result in the loss of coconut fruit bunches yearly. Investigations into achieving drying techniques that result in optimum drying rates coupled with consumer's desired end products that are both commercially and nutritionally viable remain paramount in the food industry. Consequently, osmotic dehydration is commendable for its low-cost pretreatment merit. Therefore, the study examined the drying-kinetics, energy consumption, effective moisture diffusivity (D_{eff}), vitamin C retention, color, and rehydration behavior of coconut cultivars (Sri Lanka Green Dwarf × Vanuatu Tall (SGD × VTT), Catigan (CAT), and Tacunan Green Dwarf (TGD)) meat slices. Samples were osmotically pretreated with sucrose solution (30 %/30 min) and subjected to oven drying (80, 90, 100, and 110 °C (air velocity of 2 m/s) and lyophilization (−45 ± 2 °C) methods. A mathematical model was employed to predict the effect of osmotic pretreatment on drying dynamics and the assessment of utilized energy, vitamin C content, color, and rehydration of coconut meat slices at different drying conditions. The oven-dried sample's color changed ($p < 0.05$) compared to lyophilized samples. Drying-kinetics models were validated using determination coefficient (R^2) and root mean square error (RMSE). The Asymptotic model satisfactorily suited the samples' drying data goodness fitting based on $R^2 \geq 0.90 - 0.99$ and low RMSE $\leq 0.01 - 0.12$ compared to other models for both drying methods. D_{eff} ranged between 1.10×10^{-07} m^2s^{-1} and 7.90×10^{-08} m^2s^{-1} for all the drying methods. CAT sample retained high vitamin C content compared to SGD × VTT and TGD samples. Rehydration ratio values were significant at lower temperatures among oven-dried experimental samples whereas TGD samples exhibited a significant rehydration values compared to SGD × VTT and CAT lyophilized samples. Among the drying methods, oven drying exhibited low energy consumption with shorter drying time and optimum D_{eff} per adopted temperature ranges compared to lyophilization. The study revealed that temperature, time, the sucrose solution, and the thickness of the coconut slices strongly influenced the drying kinetics of the osmotically pre-treated coconut meat slice's drying features.

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1. Introduction

In tropical climates of the world, coconuts (*Cocos nucifera* L.) are frequently found to be grown near sandy shorelines [1]. As the coconut develops, endosperm cellular layers are deposited along its sides and eventually turn into the coconut's edible "meat" and the dried coconut meat is known as copra [2]. The mature fruit contains 12 % hard shell, 25 % coconut water, 28 % meat, and 35 % thick husk [3]. Dried coconut almonds, coconut milk, coconut flour, and coconut juice are just a few of the many ways that coconut is processed and used in food. Coconut consumption has been related to a variety of health benefits, including; lower risk of heart disease, support for weight loss due to high fibers that increase fullness, improved digestion, stability of blood sugar levels, and improved immunity [4–6]. Conversely, poor postharvest and preservation methods result in the annual loss of coconut fruit bunches. As a result, processing these fruits with an added value is given more importance to mitigate losses. However, without chemicals, the shelf-life of the copra is reduced to fewer days and one of the common preserving procedures has been drying [7]. Fruits are purposefully dried to control moisture content to enhance their nutritional and organoleptic qualities, likewise extending their shelf-life during storage. But sun drying process is time-consuming, expensive, and prone to microbes due to unclean exposures [8]. Furthermore, Tunde-Akintunde [9] reported that direct sunshine can significantly reduce the quantity of components like vitamins in the dried product. Fruit slices are dehydrated in two steps: first, water is removed using an osmotic agent, or osmotic concentration, and then the product is further dehydrated (in the freezer or oven) to further lower its moisture content and make it shelf-stable. Lyophilization process involves water sublimation by the direct transition of water from solid (ice) to vapor [10,11]. Thus, under low pressure the liquid in a product is removed resulting in the inhibition of the products microbiological, chemical, and biochemical actions to retain product quality [10]. Lyophilization as an efficient drying method is associated with numerous key functionalities such as appropriate rehydration rate due to a product porous tissue, effectiveness to stabilize color, texture, and nutritional value of samples [12]. Because of the low temperature and the water removal process, lyophilization delivers a minimum thermal breakdown of nutrients [10].

Yet, osmotic dehydration is one instance of a low-cost pretreatment [13]. Importantly, conditions that result in optimum drying rates are desired to create acceptable end products that are both commercially and nutritionally viable. Osmotic pretreatment benefits include better end-product quality and less energy use. Osmotic agents such as glucose, fructose, sucrose, trehalose, sorbitol is reported to impact the physicochemical attributes, effective diffusivity, and mas transfer rate of fruits and vegetables [14]. Osmosis and the addition of sugar are two instances of how the transfer of mass can alter the end product's physical, chemical, nutritional value, flavor, and structural attributes [15]. The effect of pretreatment techniques on color, rehydration ratio, and drying characteristics have been studied on yam chips [16] and eggplants [17]. Accordingly, osmotic pretreatment has been explored on young coconut for an enhanced drying kinetics [18]. Additionally, modelling the process of parameters is vital to designing, predicting, and improving the outcomes of the experimental process [19]. Thus, the kinetics of drying coconuts under various drying settings have been predicted using mathematical model equations [20]. This study was aimed at the following; - (1) to employ a mathematical model to predict the effect of osmotic pretreatment on drying dynamics. (2) to assess energy utilization, vitamin C content, color, and rehydration of coconut meat slices at different drying conditions.

2. Materials and methods

2.1. Materials

The studies were conducted in a pilot laboratory of the University of Energy and Natural Resources, (Sunyani, Ghana) and the Council for Scientific and Industrial Research (CSIR); Oil Palm Research Institute (OPRI) (Kade, Ghana). Three physiologically matured (11–12 month) coconut (*Cocos nucifera* L.) cultivars namely; SGD × VTT, CAT, and TGD were supplied by the Council for Scientific and Industrial Research (CSIR); Oil Palm Research Institute (OPRI) demonstration farms (Kade, Ghana) located at 6° 04′ 60.00″ North latitude and 0° 49′ 59.99″ East longitude. Chemicals and reagents employed in the study were supplied by the pilot laboratory and were of analytical grade.

2.2. Preparation of samples

The coconut fruits devoid of mechanical, physical, and fungal damage were selected. Coconuts were manually cracked open with a stainless-steel kitchen hammer by striking perpendicularly across the ridge mid-way to break off the brown, fibrous husk which conceal the meat inside. Coconut meat samples were gently removed from the attached inner shell with a ceramic kitchen knife (CK 10A/4.8, Dolphin series, CREASHARP China) by firmly pressing, twisting, and turning the ceramic knife tip in a cylindrical direction. Subsequently, coconut meat samples were washed and cleansed with distilled water. To prepare the samples for drying, coconut meat was sliced into 1.5 cm long, 1 cm wide, and 1 cm thick pieces using the ceramic knife.

2.3. Experimental plan

The coconut cultivars namely; SGD × VTT, CAT, and TGD meat slices osmotically pretreated served as the three experimental treatment groups and were subjected to two different drying conditions namely; oven drying and lyophilization. For the oven drying treatment, SGD × VTT, CAT, and TGD were each subjected to temperature regimes of 80, 90, 100 and 110 °C. For the lyophilized treatment, SGD × VTT, CAT, and TGD were lyophilized (−45 ± 2 °C) for 48 h. The summary of the steps taken to experiment is shown in Fig. 1.

2.4. Osmotic pretreatment and dehydration

The modified method outlined by Kumar and Sagar [21] was adopted for sample osmotic pretreatment. Briefly, coconut meat slices were suspended in a 500 ml glass beaker containing a sugar (sucrose) solution of 0.1 % citric acid and 0.05 % potassium metabisulphite (KMS) as the osmotic solute. The sucrose solution for osmotic pretreatment was maintained at a pre-set value of temperature (60 °C) and sugar concentration (60 °Brix). The coconut meat slices were kept in a beaker holding osmotic solution at a 1:4 sample to solution (w/w) ratio to achieve better soaking of samples. After immersing coconut meat slices for 30 min, samples were withdrawn from the osmotic solution, drained quickly, and moped gently with absorbent paper to dry samples from the excess sugar solution.

The osmotic dehydration method of Agarry and Aworanti [22] was adopted with slight modification to evaluate the weight loss (WR), solute gain (SG), and water content loss (WL) of coconut meat slices. The formulae below were used to calculate samples WR, SG, and WL respectively.

$$WR = \frac{M_f - M_o}{M_o} \quad \text{Eq. (1)}$$

$$SG = \frac{m_f - m_o}{M_o} \quad \text{Eq. (2)}$$

$$WL = \frac{(M_o - m_o) - (M_f - m_f)}{M_o} \quad \text{Eq. (3)}$$

where: M_o represents the initial fresh coconut meat weight (g) before osmotic treatment; M_f represents the final weight of coconut (g) after osmotic treatment time (t); m_o represents the coconut meat dry weight (g); and m_f represents the final dry weight of coconut meat after osmotic treatment (g).

2.5. Oven drying and lyophilization of pretreated coconut meat slices

The method of AOAC [23] was employed to determine the initial moisture content of the osmotic pretreated coconut meat slice by vacuum drying (70 °C/24 h) and noted as 51.6 ± 06 % wet basis. An electric scale (model SL2002N, Shijiazhuang, China) of ±0.01 g sensitivity was used for measuring samples. Further, an electric oven dryer (SLN 75 POL-EKO-APPARATURA, Śląski, Poland) was used for the drying process of osmotically pretreated coconut meat slices. The electric oven dryer comprised a tray chamber, an electric heater, a fan, and a temperature controller (dry bulb temperature range: 50–350 °C). To establish stable ambient condition before loading samples, the oven dryer was allowed to achieve a steady state at set points for 30 min. A 300 g of osmotically pretreated

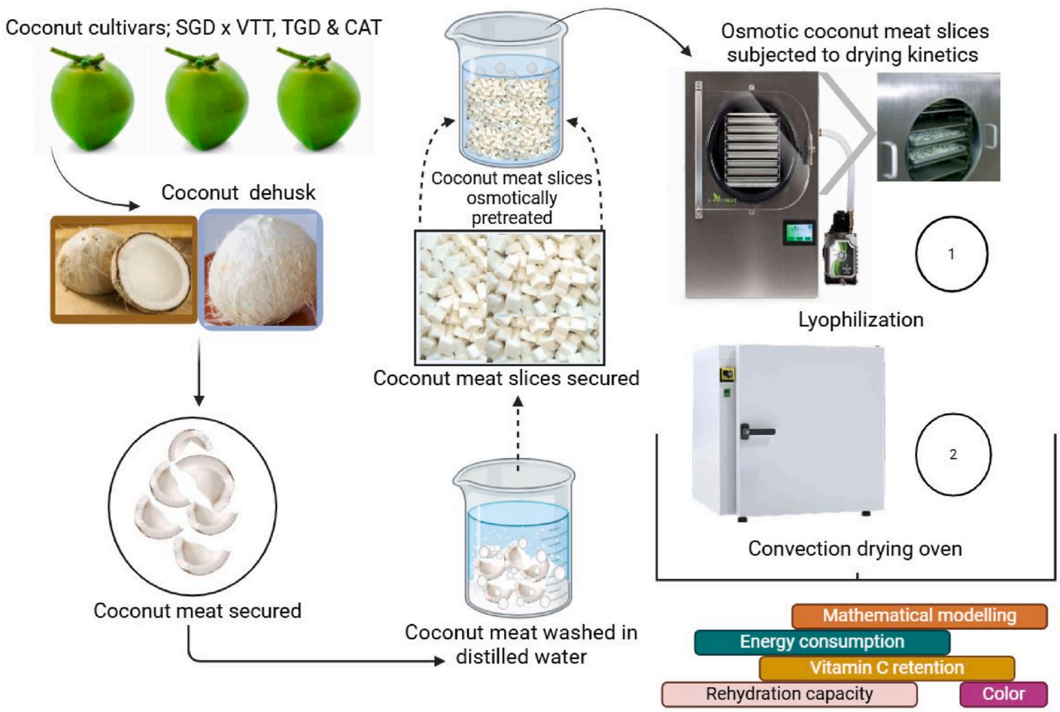

Fig. 1. A Schematic illustration of the treatment designs of coconut meat slices.

samples were evenly spread on a stainless-steel sieve tray and dried with an air velocity of 2.0 ms^{-1} at variable temperatures (80, 90, 100 and 110 °C) and at different ending times (10–16 h).

A 300 g of osmotic pretreated coconut meat samples were placed into the freeze-drying chamber (Thermo Scientific Savant Micromodulyo freeze dryer, North Carolina, USA) for each drying experiment. The plate temperature was set at 10 °C to hasten the sublimation process, prevent product melting, while in operation, and maintain a constant temperature throughout the drying process. New samples of equal mass were used in each experiment for a progressively longer time, and moisture loss was determined by accurately weighing the Petri dishes on a digital scale to the nearest 0.01 g. The coconut meat slices were frozen at −45 ± 2 °C for 48 h and the weight of the sample was determined every 6 h until a constant weight was achieved. The dried slices were stored at 20 °C in glass jars (in the dark) until later analysis.

2.6. Kinetics modelling

The drying theory of Lewis [24] based on Newton's law of cooling often adopted to explain the mass transfer in a thin layer of agricultural products per Eq. (4) was used.

$$MR = \frac{M_t - M_e}{M_o - M_e} = exp\,(-kt) \qquad \text{Eq. (4)}$$

Where MR represents moisture ratio, M_t signifies the moisture content at different time (t) intervals (g water/g dry matter), M_o denotes the initial moisture content, M_e represents equilibrium moisture contents on a dry basis, and k denotes the drying constant. M_e was assumed to be zero in dry base (d.b) for MR analysis. As indicated in Eq. (4), the experimental set (MR, t) was fitted into five thin layer drying models in Table 1 to estimate the goodness of fit of the empirical models that best describe the drying data of the dehydrated coconut meat slices. Model regression analysis was performed using Origin-Pro 9.2 (Origin Lab Corporation, Northampton, MA, USA). The primary parameters including the coefficient of determination (R^2), reduced Chi-square (χ^2), and root mean square error (RMSE) were used to assess the best-fitting model parameter using the equations below.

$$R^2 = \frac{N\sum_{i=1}^{N} MR_{pred,i}MR_{expt,i} - \sum_{i=1}^{N} MR_{pred,i}\sum_{i=1}^{N} MR_{expt\ x,i}}{\sqrt{\left(N\sum_{i=1}^{N} MR_{pred,i}^2 - \left(\sum_{i=1}^{N} MR_{pred,i}\right)^2\right)\left(N\sum_{i=1}^{N} MR_{expt,i}^2 - \left(\sum_{i=1}^{N} MR_{expt,i}\right)^2\right)}} \qquad \text{Eq. (5)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(MR_{expt,i} - MR_{pred,i}\right)^2} \qquad \text{Eq. (6)}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{expt,i} - MR_{pred,i}\right)^2}{N - z} \qquad \text{Eq. (7)}$$

where N represents the number of observations, z represents the number of constants, and $MR_{expt,i}$ represents experimental dimensionless MR, $MR_{pred,i}$ represents predicted dimensionless MR. The model with the highest R^2 and the least $RMSE$ and χ^2 values were chosen to reflect the best drying kinetics of osmotic pretreated coconut meat slices at varied temperatures [25].

2.7. Effective moisture diffusivity (D_{eff})

The D_{eff} of dried osmotic pretreated coconut meat slices was calculated under the following conditions: a constant diffusion coefficient, one-dimensional moisture movement, constant temperature, and minimal external resistance for effective moisture diffusivity (D_{eff}). Therefore, the diffusional model of Fick's second law for various geometries employed in the biological materials drying process during the era of the dropping rate as shown in Eq. (8) was applicable in the study.

$$\frac{\partial M}{\partial t} = D_{eff}\nabla^2 M \qquad \text{Eq. (8)}$$

The equation is of the form:

Table 1
Selected mathematical models adopted to simulate osmotically coconut meat slices drying process.

Model Name	Model equation	References
Lewis	$MR = \exp(-kt)$	[24]
Page	$MR = \exp(-kt^n)$	[26]
Modified page	$MR = \exp[(-kt)^n]$	[27]
Wang and Singh	$MR = 1 + at + bt^2$	[28]
Asymptotic	$MR = a - b \times c\exp(t)$	[29]

$$MR = \frac{M\text{-}M_e}{M_o\text{-}M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n\text{-}1)^2}\exp\left[\text{-}\frac{(2n\text{-}1)^2\pi^2 D_{eff}\, t}{4L^2}\right] \quad \text{Eq. (9)}$$

Where *MR* represents moisture ratio, *M* represents average moisture content (g/g d.b), M_o represents initial moisture content (g/g d.b), M_e represents equilibrium moisture content (g/g d.b) all at a different time (*t*), *L* represents half the thickness of the coconut meat slices, *t* represents drying time, and D_{eff} represents constant effective diffusion coefficient ($m^2\ s^{-1}$). Eq. (10) can only be utilized with the first component for sufficiently long-term drying.

$$MR = \frac{\boldsymbol{M_t}}{\boldsymbol{M_0}} = \frac{8}{\pi^2}\,\boldsymbol{exMRp}\left(-\frac{\pi^2 D_{eff}\ t}{4L^2}\right) \quad \text{Eq. (10)}$$

D_{eff} is commonly estimated by graphing the experimental moisture ratio against the drying time in a logarithmic manner. The slope ($\boldsymbol{k_0}$) is estimated by plotting (*MR*) against time (*t*).

$$\boldsymbol{k_0} = \frac{\pi^2 D_{eff}}{4L^2} \quad \text{Eq. (11)}$$

2.8. Determination of vitamin C

The vitamin C content of coconut meat slice samples was determined by a titration method. Dichlorophenol indophenol was utilized as an indication to find the titration endpoint. Using a Gallenhamp Magnetic Stirrer Hotplate Model 400 for 8 m, a 20 g blended sample diluted with a 10 ml solution of metaphosphoric acid was further heated. The 2,6-dichloroindophenol was titrated to a definite rose-pink endpoint using the dye-titration procedure as specified in AOAC [23] which entailed extraction with a 3 % metaphosphoric acid solution. Vitamin C determination was conducted in triplicate.

2.9. Color determination

The color of dried coconut meat samples that had undergone osmotic pretreatment was evaluated using a colorimeter (DC-P3, Beijing, China) equipped with illuminant D65. Evaluation of color indicators including L^* value for lightness, a^* value for redness, and b^* value for yellowness was done using the method in its entirety as stated in Ref. [7]. Total color variations were displayed using the total color difference (ΔE), which was calculated using Eq. (12).

$$\Delta E^* = \sqrt{\left(\boldsymbol{L_0^*} - \boldsymbol{L^*}\right)^2 + \left(\boldsymbol{a_0^*} - \boldsymbol{a^*}\right)^2 + \left(\boldsymbol{b_0^*} - \boldsymbol{b^*}\right)^2} \quad \text{Eq. (12)}$$

where L_0, a_0, and b_0 are the values of dried coconut samples.

2.10. Determination of rehydration ratio

Rehydration ratio method outlined by Salehi et al. (2023c) [30] was employed with slight modification to conducted rehydration on the oven and lyophilized coconut meat samples. 5 g of dried samples was submerged in 100 mL distilled water for 6 h at 25 °C. At 1 h intervals, samples of coconuts were removed from the water bath, blotted with absorbent paper, and then weighed on an electric scale (model SL2002N, Shijiazhuang, China). The rehydration ratio values (%) of dehydrated coconut meat was evaluated as the ratio of the final weight of rehydrated coconut meat over the dried coconut × 100.

2.11. Energy consumption

To determine the energy needed to dry the coconut meat samples, the energy consumption method described by Sarpong et al. (2022) [3] was employed for samples energy consumption estimation. Briefly, the total energy consumption was evaluated through electric energy meter with 0.01 kWh accuracy and calculated using Eq. (13).

$$Es = \frac{Et}{Ww} \times 100 \quad \text{Eq. (13)}$$

Where *Es* represents the specific energy consumption, *Et* represents the total energy consumption, and *Ww* represents the initial weight of samples (g).

2.12. Statistical analysis

Data from the studies were analyzed using Origin-Pro 9.2 (Origin Lab Corporation, Northampton, MA, USA) and all experiments were replicated. One-way ANOVA and Pearson's correlation coefficient were utilized to further examine the statistical distinction between the treatments ($p < 0.05$) and Mean ± Standard deviations were used to express the data.

3. Results and discussions

3.1. Drying curve

Fig. 2(A–D) shows the evolution plot of the convective and lyophilization impacts on the samples' moisture ratio. Generally, the oven-dried samples revealed an MR trend of decreasing with the increasing drying time. Also, an increase in temperature resulted in a reduced drying time. Hence, time and temperature had a significant effect on oven samples MR because the mechanism of moisture removal relates to a higher drying rate of the convection stream. In that, air and thermal streams easily removed moisture from samples but at an increased temperature with reduced time and vice-versa. According to Fernando and Amarasinghe [31], a higher volume expansion of the sample is achieved when samples are dried at low temperatures but at a cost of a longer drying time. Also, the relation of time with continuous MR reduction revealed that coconut meat interior mass transfer was governed by diffusion as similarly reported by Agarry and Aworanti [22] among coconut strips. Further, the pattern of results reveals a significant variation among CAT and TGD meat slices MR compared to the SGD × VTT sample. The effect of lyophilized samples generally required a longer drying duration, however, the removal of bound water content from SGD × VTT sample was lower compared to the more efficient MR of CAT and TGD samples. Thus, freeze drying mechanism time and energy donate latent heat of sublimation to change ice into water [32]. Comparatively, the oven drying method was more effective among samples MR than lyophilized treated samples as moisture content removal remains a major factor in measuring the two drying methods kinetics. Depending on factors like the temperature of the drying media and air velocity, freeze-drying used longer drying durations than convective drying. This resulted in weight loss during the initial phases of drying and the moisture content gradually decreased as drying time increased.

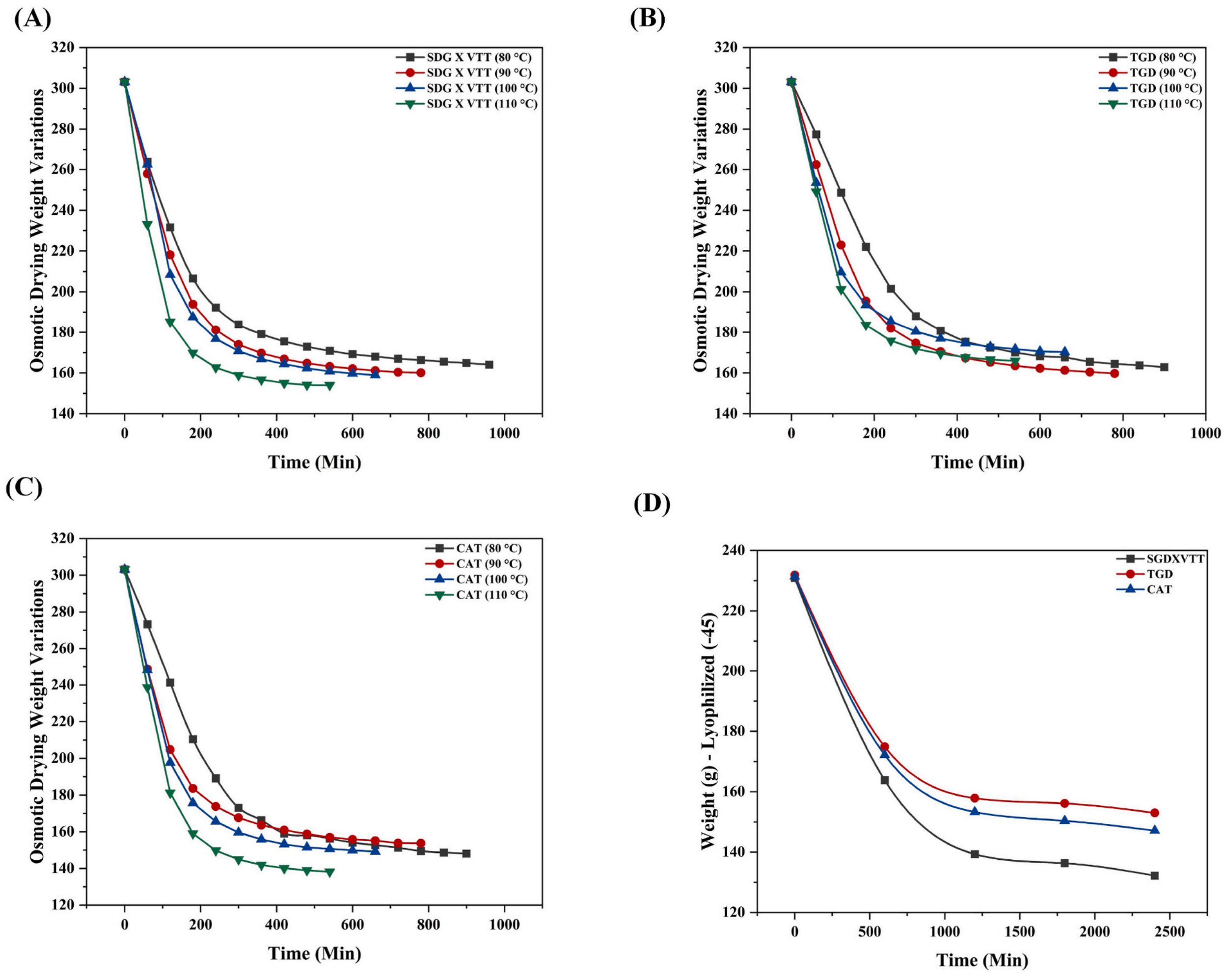

Fig. 2. Effect of drying on weight variations of osmotically dehydrated coconut meat slices. **(A)** Drying curve of oven-dried SGD × VTT; **(B)** Drying curve of oven-dried TGD; **(C)** Drying curve of oven-dried CAT; **(D)** Lyophilized samples. TGD: Tacunan Green Dwarf variety; CAT: Catigan variety; SGD × VTT: Sri-Lanka Green Dwarf × Vanuatu Tall cross breed. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

3.2. Mass transfer determination

Osmotic pretreatment influences drying dynamics and product quality whereas lower energy requirement is of beneficial effect. Therefore, osmotic dehydration's effects on oven-dried and lyophilized samples are displayed in Table 2. The CAT samples recorded a high WR and SG values than WL compared to SGD × VTT and TGD samples for both oven drying and lyophilized method. A fluctuating result was observed. According to Cichowska et al. [33], high water loss coupled with low solid gains signifies a good functionality of pretreatment. Therefore, the oven drying and lyophilized methods revealed low SG values but with a slightly higher value of 13.6 % (SG) among lyophilized SGD × VTT samples. Thus, the recorded SG value indicates a satisfactory performance of osmotic pretreatment because sugar gain reveals the quantity of soluble solids gained by the sample during pretreatment. The low WL and WR values of samples revealed a progressive effect of osmotic solution and concentration with temperature. Although the results demonstrated an inconsistent pattern of a swift reduction or increase in value relative to increased temperatures among the samples. Yet, the dried samples during osmotic dehydration proved the viability of the pre-processing technique. In brief, at a constant sucrose content (30 %) without a progression of immersion time (30 min), the samples' showed a variable WR, WL and SG of osmotic mass transfer as the osmotic processing temperature rose. TGD and CAT showed variable WR and WL increased along the temperature range and at a constant sucrose content/concentration. Results were inconsistent with higher WR and WL reported for osmosed coconut strip samples Agarry and Aworanti [22] and increased WL and SG papaya cut samples subjected to osmotic dehydration at different immersion times [34]. Conversely, the SG results corroborated with Cichowska et al. [33] report of low SG among Apples. Hence, the osmotic dehydration of the present study samples at different times and samples immersion time during pretreatment could have influenced the sugar solution concentration gradient functionality on the sample to reveal a clearer trend of osmotic dehydration among WR and WL parameters.

3.3. Best fit models

Table 3 displays the findings that suit the goodness of fit for the three primary statistical parameters (R^2, RMSE, and χ^2) among the examined models for oven and freeze-drying conditions. To establish the best fit, the primary criterion R^2 should be close to 1 whereas the values of RMSE and χ^2 should be close to 0. Comparatively, all examined models showed either high or low values for specific statistical parameters but their tendency to correlate with the model's goodness of fit requirement ($R^2 \geq 0.90$, low RMSE ≤ 0.009 and $\chi^2 \leq 0.009$) was not relative. Wang and Singh's model R^2 values were close to 1 but RMSE was higher than 0. Accordingly, the Modified Page and Lewis model R^2 and RMSE values were low and higher than their empirical requirement. This observation corroborates with Ah-Hen et al. [35] report that an increase in drying air temperature influenced kinetic parameters value. Conversely, the Asymptotic model exhibited satisfactory R^2 and RMSE values relative to $R^2 \geq 0.90$ and low RMSE ≤ 0.009 indicating its appropriateness to describe the drying behavior of coconut meat slices at 80–110 °C temperature. However, the χ^2 values displayed entirely among the examined models were averagely high with $\chi^2 \leq 0.009$ compared to low χ^2 values (0.52671–16.8409) reported in similar studies by Sarpong et al. [3]. Therefore, since χ^2 reveals the mean square of deviation among the experimented and predicted values for models, the observed increased χ^2 values could be inferred that although at 80–110 °C conditions the R^2 and RMSE values of the Asymptotic model allowed an accurate simulation of the coconut varieties. But the concentration of the osmotic treated coconut meat slices with the hot air velocity could not effectively affect the experimental treatment's χ^2 values. Thereby, the high χ^2 values of the Asymptotic model were a less good option to fit the experimental data compared to the findings of Sarpong et al. [3]. But the other models were

Table 2
Osmotic dehydration of oven and lyophilized sample and selected mathematical modelling for osmotically dried coconut meat slices.

Coconut Variety/Temp (°C)	Osmotic Pretreatment Condition	Sample Weight (g)	WR (%)	WL (%)	SG (%)
SGD × VTT					
80	80 °C, 30 % (w/w)	300	3.4 ± 0.02^b	1.1 ± 0.02^c	7.9 ± 0.01^b
90	90 °C, 30 % (w/w)	300	1.8 ± 0.00^d	1.6 ± 0.03^c	5.3 ± 0.00^c
100	100 °C, 30 % (w/w)	300	2.6 ± 0.02^c	2.6 ± 0.00^b	4.5 ± 0.02^d
110	110 °C, 30 % (w/w)	300	0.6 ± 0.01^e	0.1 ± 0.01^d	1.2 ± 0.00^e
Lyophilized	30 % w/w	300.03	4.2 ± 0.03^a	12.0 ± 0.02^a	13.6 ± 0.01^a
TGD					
80	80 °C, 30 % (w/w)	300	2.3 ± 0.00^b	1.9 ± 0.02^d	6.5 ± 0.02^b
90	90 °C, 30 % (w/w)	300	0.8 ± 0.02^c	3.5 ± 0.01^c	5.0 ± 0.00^c
100	100 °C, 30 % (w/w)	300	4.2 ± 0.01^a	3.7 ± 0.00^c	11.9 ± 0.01^a
110	110 °C, 30 % (w/w)	300	0.9 ± 0.01^c	6.9 ± 0.02^b	1.7 ± 0.00^d
Lyophilized	30 % w/w	300.05	4.1 ± 0.03^a	11.8 ± 0.01^a	0.1 ± 0.02^e
CAT					
80	80 °C, 30 % (w/w)	300	2.3 ± 0.01^b	5.4 ± 0.02^b	3.0 ± 0.02^c
90	90 °C, 30 % (w/w)	300	0.8 ± 0.00^d	0.6 ± 0.01^d	1.1 ± 0.00^d
100	100 °C, 30 % (w/w)	300	1.4 ± 0.02^c	5.0 ± 0.02^b	2.7 ± 0.02^c
110	110 °C, 30 % (w/w)	300	1.1 ± 0.01^c	6.1 ± 0.00^a	7.0 ± 0.01^a
Lyophilized	30 % w/w	300.03	4.9 ± 0.01^a	4.3 ± 0.01^c	3.7 ± 0.03^b

Values are means ± standard deviation ($n = 3$); Different letters in the same column indicate significant differences ($P < 0.05$); Temp: Temperature; SGD × VTT: Sri Lanka Green Dwarf × Vanuatu Tall cross breed; CAT: Catigan; TGD: Tacunan Green Dwarf; Lyophilized: −45 ± 2 °C; WR: Weight Reduction; WL: Water Content Loss; SG: Sugar Gain.

Table 3
Models' coefficients for oven-dried and lyophilized coconut meat slices.

Temperature (°C)	Model Name	Constant			R^2	χ^2	RMSE
SGD × VTT							
80	Lewis	k = 0.008			0.70	8.70	2.95
	Page	$k = -9.408 \times 10^{-5}$	n = 1.700		0.72	3.46×10^{-04}	0.02
	Modified page	$k = 3.944 \times 10^{-4}$	n = 0.003		0.71	0.84	0.92
	Wang and Singh	a = −0.357	$b = 2.618 \times 10^{-4}$		0.92	144.67	12.03
	Asymptotic	a = 165.296	b = −139.768	c = 0.994	0.90	3.21	0.01
90	Lewis	k = 0.008			0.70	8.70	2.95
	Page	k = −0.000	n = 1.690		0.60	5.04×10^{-04}	0.22
	Modified page	k = 0.003	$n = 3.921 \times 10^{-4}$		0.71	0.83	0.91
	Wang and Singh	a = −0.382	$b = 2.966 \times 10^{-4}$		0.89	196.11	14.00
	Asymptotic	a = 161.653	b = −144.436	c = 0.992	0.90	7.17	0.01
100	Lewis	k = 0.011			0.69	9.34	3.06
	Page	$k = -1.571 \times 10^{-4}$	n = 1.705		0.74	4.50×10^{-04}	0.02
	Modified page	k = 0.004	$n = 7.01 \times 10^{-4}$		0.699	0.896	0.947
	Wang and Singh	a = −0.573	$b = 6.022 \times 10^{-4}$		0.936	167.044	12.93
	Asymptotic	a = 158.294	b = −149.396	c = 0.992	0.989	27.955	0.01
110	Lewis	k = 0.011			0.690	9.026	3.01
	Page	$k = -1.366 \times 10^{-4}$	b = 1.687		0.572	7.19×10^{-04}	0.03
	Modified page	k = 0.004	$n = 6.941 \times 10^{-4}$		0.702	0.878	0.94
	Wang and Singh	a = −0.599	$b = 6.803 \times 10^{-4}$		0.880	297.319	17.24
	Asymptotic	a = 155.405	b = −149.385	c = 0.988	0.996	11.194	0.01
CAT							
80	Lewis	k = 0.008			0.693	8.742	2.96
	Page	$k = -1.246 \times 10^{-4}$	n = 1.702		0.765	4.68×10^{-04}	0.02
	Modified page	$k = 3.950 \times 10^{-4}$	n = 0.003		0.707	0.840	0.92
	Wang and Singh	a = −0.426	$b = 3.062 \times 10^{-4}$		0.953	121.990	11.05
	Asymptotic	a = 145.776	b = −164.453	c = 0.995	0.992	20.056	0.01
90	Lewis	k = 0.008			0.693	8.742	2.96
	Page	$k = -1.012 \times 10^{-4}$	n = 1.686		0.679	4.75×10^{-04}	0.02
	Modified page	k = 0.003	$n = 3.913 \times 10^{-4}$		0.711	0.825	0.91
	Wang and Singh	a = −0.365	$b = 2.710 \times 10^{-4}$		0.854	288.432	16.98
	Asymptotic	a = 152.778	b = −150.793	c = 0.992	0.993	11.460	0.01
100	Lewis	k = 0.011			0.685	9.204	3.03
	Page	$k = -1.682 \times 10^{-4}$	n = 1.697		0.719	5.70×10^{-04}	0.02
	Modified page	k = 0.004	$n = 6.983 \times 10^{-4}$		0.698	0.888	0.94
	Wang and Singh	a = −0.606	$b = 6.472 \times 10^{-4}$		0.927	208.791	14.45
	Asymptotic	a = 148.959	b = −156.876	c = 0.991	0.996	12.042	0.01
110	Lewis	k = 0.011			0.692	9.330	3.05
	Page	$k = -1.312 \times 10^{-4}$	n = 1.704		0.707	3.67×10^{-04}	0.02
	Modified page	k = 0.004	$n = 7.012 \times 10^{-4}$		0.702	0.896	0.95
	Wang and Singh	a = −0.511	$b = 5.441 \times 10^{-4}$		0.918	169.589	13.02
	Asymptotic	a = 170.922	b = −133.906	c = 0.991	0.996	8.675	0.02
TGD							
80	Lewis	k = 0.008			0.698	8.845	2.97
	Page	$k = -1.076 \times 10^{-4}$	n = 1.709		0.773	3.33×10^{-04}	0.02
	Modified page	$k = 3.964 \times 10^{-4}$	n = 0.003		0.710	0.846	0.92
	Wang and Singh	a = −0.383	$b = 2.728 \times 10^{-4}$		0.959	88.141	9.39
	Asymptotic	a = 160.388	b = −149.157	c = 0.995	0.993	14.796	0.01
90	Lewis	k = 0.008			0.698	8.845	2.97
	Page	$k = -9.278 \times 10^{-5}$	n = 1.693		0.634	4.86×10^{-04}	0.02
	Modified page	k = 0.003	$n = 3.927 \times 10^{-4}$		0.712	0.831	0.91
	Wang and Singh	a = −0.386	$b = 2.948 \times 10^{-4}$		0.901	189.399	13.76
	Asymptotic	a = 160.649	b = −146.421	c = 0.993	0.995	9.087	0.02
100	Lewis	k = 0.011			0.692	9.330	3.06
	Page	$k = -1.313 \times 10^{-5}$	n = 1.704		0.707	3.67×10^{-04}	0.02
	Modified page	k = 0.004	$n = 7.012 \times 10^{-4}$		0.703	0.896	0.95
	Wang and Singh	a = −0.511	$b = 5.441 \times 10^{-4}$		0.918	169.589	13.02
	Asymptotic	a = 170.922	b = −133.906	c = 0.991	0.996	8.675	0.01
110	Lewis	k = 0.011			0.692	9.209	3.03
	Page	$k = -1.279 \times 10^{-4}$	b = 1.697		0.613	5.32×10^{-04}	0.02
	Modified page	k = 0.004	$n = 6.984 \times 10^{-4}$		0.703	0.888	0.94
	Wang and Singh	a = −0.561	$b = 6.267 \times 10^{-4}$		0.908	202.767	14.34
	Asymptotic	a = 166.715	b = −139.231	c = 0.989	0.993	16.513	0.02
Lyophilized							
SGD × VTT	Lewis	k = 0.003			0.650	10.636	3.261
	Page	$k = -4.047 \times 10^{-5}$	n = 1.662		0.730	6.12×10^{-04}	0.025
	Modified page	$k = 9.041 \times 10^{-4}$	$n = 2.886 \times 10^{-4}$		0.662	1.056	1.028
	Wang and Singh	a = −0.112	$b = 3.202 \times 10^{-5}$		0.945	138.116	11.752

(*continued on next page*)

Table 3 (*continued*)

Temperature (°C)	Model Name	Constant			R^2	χ^2	RMSE
	Asymptotic	a = 131.347	b = −99.657	c = 0.998	0.998	2.747	0.0123
CAT	Lewis	k = 0.003			0.659	10.772	3.282
	Page	$k = -2.872 \times 10^{-5}$	n = 1.66911		0.686	3.81×10^{-04}	0.020
	Modified page	$k = 9.196 \times 10^{-4}$	$n = 2.898 \times 10^{-4}$		0.668	1.064	1.032
	Wang and Singh	a = −0.090	$b = 2.612 \times 10^{-5}$		0.928	114.579	10.704
	Asymptotic	a = 152.773	b = −79.100	c = 0.997	0.999	1.412	0.013
TGD	Lewis	k = 0.003			0.657	10.739	3.277
	Page	$k = -3.185 \times 10^{-5}$	n = 1.66751		0.706	4.26×10^{-04}	0.021
	Modified page	$k = 9.156 \times 10^{-4}$	$n = 2.895 \times 10^{-4}$		0.667	1.062	1.031
	Wang and Singh	a = −0.096	$b = 2.761 \times 10^{-5}$		0.938	112.988	10.630
	Asymptotic	a = 146.729	b = −84.712	c = 0.998	0.999	1.019	0.015

SGD × VTT: Sri Lanka Green Dwarf × Vanuatu Tall cross breed; CAT: Catigan; TGD: Tacunan Green Dwarf; Lyophilized: −45 ± 2 °C; R^2: coefficient determination; RMSE: root means square error; χ^2 reduced chi-square; k, a, b, n, and c: kinetic constants.

revealed to be weaker model compared to the Asymptotic model consistent with high R^2 values and low RMSE values relative to $R^2 \geq 0.90$, low RMSE ≤ 0.009 for predicting the best-fit model for this maiden study of osmosed coconut meat slices drying kinetics.

3.4. *Optimum energy consumption and effective moisture diffusivity*

Table 4 reveals the observed amount of energy consumed for drying osmosed coconut meat slices during oven drying at various temperatures (80–110 °C) and lyophilized conditions. The energy consumption values of oven-dried samples exhibited an inverse trend of results such that the lower the temperature, the higher the energy consumption rate. Yet, the oven-dried samples values (281–499 kWh/Kg) range was the amount of energy required to maintain a constant dry weight of coconut meat slices under the 80–110 °C conditions. This could be inferred that the relationship between air velocity, drying time, and temperature conformed to a significant impact on energy use. According to Zhao et al. [36], different thicknesses of samples play a role in the energy consumption of the drying system. Thus, variations in the same temperature of the osmosed coconut meat slices affected the quantity of energy utilized during the drying process. In a similar case, a decreased drying time was relative to an increased temperature because the rate of specific energy use decreased. However, the oven drying technique recorded a low energy usage of 499 kWh/kg with a substantial difference at 80–110 °C conditions compared to the freeze-drying settings of 683 kWh/kg. Further, to assess the rate of water loss for both oven-drying and lyophilization, the computed values in Table 4 describe the driving force in the drying system. Therefore, the

Table 4
Energy consumption, effective moisture diffusivity, and color effects for osmotic oven-dried and lyophilized coconut meat slice.

Temp (°C)	Variety			D_{eff} (m^2s^{-1})	EC (kWh/kg)	Color		
						L*	a*	b*
Oven-drying								
80	SGD × VTT	TGD	CAT	–	499	–	–	–
90	SGD × VTT	TGD	CAT	–	406	–	–	–
100	SGD × VTT	TGD	CAT	–	343	–	–	–
110	SGD × VTT	TGD	CAT	–	281	–	–	–
Lyophilize								
−45 ± 2	SGD × VTT	TGD	CAT	–	683	–	–	–
Oven-drying								
80	SGD × VTT			7.90×10^{-08}	–	67.40 ± 0.01^a	3.74 ± 0.03^d	11.04 ± 0.03^c
90	SGD × VTT			7.90×10^{-08}	–	61.02 ± 0.04^a	4.00 ± 0.11^c	13.12 ± 0.50^b
100	SGD × VTT			1.13×10^{-07}	–	54.50 ± 0.05^b	6.24 ± 0.50^b	15.05 ± 0.20^a
110	SGD × VTT			1.12×10^{-07}	–	43.00 ± 0.24^c	7.38 ± 0.10^a	11.06 ± 0.10^c
80	TGD			7.90×10^{-08}	–	65.10 ± 0.01^a	3.82 ± 0.01^b	10.70 ± 0.02^c
90	TGD			7.90×10^{-08}	–	55.80 ± 1.02^b	3.94 ± 0.03^b	12.50 ± 0.30^b
100	TGD			1.14×10^{-07}	–	53.30 ± 0.02^b	5.19 ± 0.50^a	13.70 ± 0.10^a
110	TGD			1.14×10^{-07}	–	11.60 ± 0.09^c	0.65 ± 0.01^c	0.70 ± 0.10^d
80	CAT			7.77×10^{-08}	–	88.30 ± 0.47^a	3.70 ± 0.10^d	11.98 ± 0.10^d
90	CAT			7.77×10^{-08}	–	80.80 ± 0.24^b	4.32 ± 0.04^c	13.70 ± 0.10^b
100	CAT			1.11×10^{-07}	–	53.40 ± 0.01^c	6.20 ± 0.10^b	14.98 ± 0.10^a
110	CAT			1.10×10^{-07}	–	45.20 ± 0.04^d	8.30 ± 0.20^a	12.70 ± 0.10^c
Lyophilize								
−45 ± 2	SGD × VTT			2.83×10^{-08}	–	60.80 ± 0.10^c	3.70 ± 0.10^a	7.30 ± 0.02^b
−45 ± 2	TGD			2.89×10^{-08}	–	66.70 ± 0.20^b	3.60 ± 0.10^b	8.30 ± 0.03^a
−45 ± 2	CAT			2.91×10^{-08}	–	68.00 ± 0.40^a	3.10 ± 0.03^c	8.10 ± 0.02^a

Values are means ± standard deviation ($n = 3$); Different letters in the same column indicate significant differences ($P < 0.05$); Temp: Temperature; D_{eff}: Effective moisture diffusivity; EC: Energy consumption; SGD × VTT: Sri Lanka Green Dwarf × Vanuatu Tall cross breed; CAT: Catigan; TGD: Tacunan Green Dwarf; *L**: lightness; *a**: redness; *b**: yellowness.

effective moisture diffusivity (D_{eff}), ranges from 1.10 × 10^{-07} to 7.90 × 10^{-08} for oven-dried samples at different temperatures and 2.83 × 10^{-08} to 2.91 × 10^{-08} for lyophilized samples. These values reveal that the study D_{eff} values were within the permissible range of food products D_{eff} values 10^{-11} to 10^{-9} m^2s^{-1} [37]. However, the value of D_{eff} in this study reduced with an increase in drying temperature among oven-dried samples. This observation corroborates with Sarpong et al. [3], report on coconut slices during convective drying. Whereas, the lyophilized samples recorded a uniform trend of D_{eff} values. According to Nasiru et al. [38]; Sarpong et al. [19] differences in food products composition, shape, structure, temperature, pretreatment, moisture threshold, and drying equipment result in a disproportion of product D_{eff} values. Also, Islam et al. [34] reported the possibility of fluctuations or inconsistencies among D_{eff} values in literature due to the variations of the food matrix, structure, and various models adopted. High D_{eff} values were recorded for oven drying compared to the lyophilized method with oven drying revealed as the most elevated effective moisture diffusivity temperature. To an extent, pretreatment and temperature influenced the D_{eff} values of samples, especially during lyophilization. This observation corroborates with Doymaz and Kocayigit [39] that the variations in drying temperatures and the structural makeup of the coconut type, have a direct impact on drying forces to evaporate free and bound water relative to the variances in D_{eff}. In this study, observed D_{eff} values could be associated with the increased resistance of temperature to sample water flux probably affected by sugar absorption, shrinkage, starch gelatinization, and carbohydrate mucilage disintegration. This was similarly adduced by Nieto et al. [40] studies among blanched and osmotically dehydrated mango during air drying.

3.5. Vitamin C

The oven drying and lyophilized conditions influence on osmosed coconut meat slices Vitamin C nutritional value is presented. As shown in Fig. 3(A–B) the vitamin C content was higher among lyophilized samples compared to oven-dried samples. Vitamin C is a water-soluble component, heat-sensitive compound, and highly oxidative that can be leached during processing and preservation. Thus, an increase in temperature could influence the vitamin C content. Therefore, vitamin C content was significantly higher among lyophilized samples compared to oven-dried samples. Also, The CAT samples recorded a higher vitamin C content for both oven-drying and lyophilized methods. However, at 90–110 °C conditions SGD × VTT showed a slightly high value of vitamin C content than TGD samples. Conversely, TGD samples at 80 °C recorded a higher vitamin C content compared to SGD × VTT samples. This could be explained that TGD samples at oven drying (80 °C) were optimum to achieve a high vitamin C content but an increase in temperature above 90 °C was also optimum for SGD × VTT and CAT to achieve a high vitamin C content. Thus, cultivar type, temperature, and drying conditions influenced the vitamin C content. Consequently, it can be inferred that the osmotic pretreatment process to an extent influenced the retention of heat sensitive compounds of Vitamin C. This finding agrees with Xiao et al. [37] report on Monukka seedless grape in an impingement dryer under various drying temperatures.

3.6. Color

Color is an intuitive nutritional and visual quality index that mainly influences consumers' patronage of products. As shown in Table 4 and Fig. 4, oven-drying altered the color of coconut meat slices from white to a darker and redder tint, which is consistent with a significant decrease in L^* value and an increase in a^* value relative to increased temperature. Any alteration in the a^* and b^* values

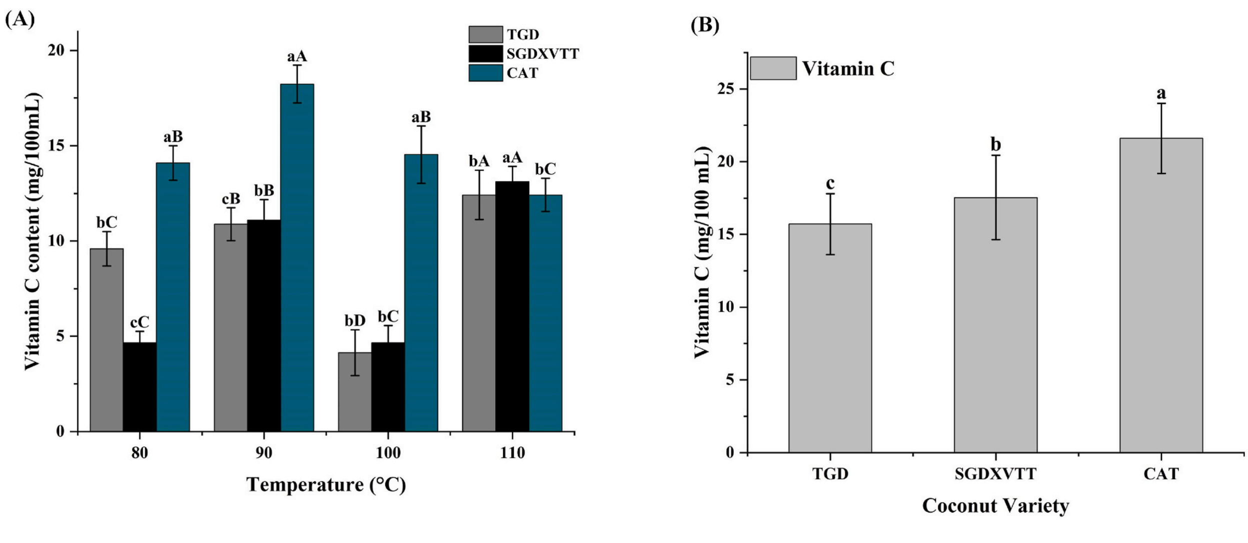

Fig. 3. **(A)** Vitamin C contents of oven dried coconut meat slices **(B)** Vitamin C contents of lyophilized coconut meat slices. TGD: Tacunan Green Dwarf variety; CAT: Catigan variety; SGD × VTT: Sri-Lanka Green Dwarf × Vanuatu Tall cross breed. Values are means ± SE (n = 3). [a-c] Mean values are significantly different ($p < 0.05$) across the treatments, whiles [A–D] means values are significantly different ($p < 0.05$). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

reflect in the L^* value. Whereas, an increase in a^* and reduction in b^* values result in the darkening of dried samples. Although, the lyophilized samples maintained the L^* value but could not be significant for a^* and b^* values. This could be explained as the degree of modification varied based on the drying conditions and the samples pigment integrity which was not broken as a result of lyophilized samples not being exposed to high temperature and highly concentrated chemical changes by the pretreatment solution. Comparatively, the oven-dried samples showed significant changes in L^*, a^*, and b^* values to the lyophilized samples. This could be inferred that the samples vitamin C content oxidized during thermal processing. According to Xu et al. [41], thermal processing causes shrinkage and structural deformation thereby resulting in photons transfer or brightness absorption. Higher temperatures favor Maillard browning reactions, which take place during air dehydration [42]. Additionally, the oxidation reaction could be a contributing factor to the variation in the color of coconut slices [7]. Therefore, the general color change (ΔE) reflects the synergistic effect of osmotic pretreatment and thermal processing. But drying temperature influenced the sample's structure demonstrating the marginal drop in color indices values.

3.7. Rehydration

The evaluation of induced damage of samples during the thermal process indicates the rehydration ratio [34]. Fig. 5(A–D) presents the rehydration ratio of the oven and lyophilized samples plot against time. Adedeji et al. [43] reported that the pretreatment mechanism results in plasmolysis which enhances water diffusion during the process of rehydration. Generally, there was an initial higher rate of absorption relative to increased time. Oven-dried samples CAT demonstrated a gradually declined absorption rate with temperature rise compared to the steady trend observed among SGD × VTT and TGD samples. This phenomenon is typically noticed among oven-dried products. According to Salehi (2023d) [44] an increase in rehydration rate of heat-treated samples is influenced by the samples higher volume and porous structure with lower shrinkage in samples therefore resulting in samples cell higher moisture diffusion. Lyophilized samples revealed a slightly higher absorption rate compared to oven-dried samples. TGD had better rehydration ratio than both SGD × VTT and CAT, which had lower initial rehydration water absorption. Rehydration is a vital approach used to analyze the quality of products and any temperature-related damage [39]. Hence, the absorption rate was shown to vary with the temperature at which the samples were dried. The study rehydration mechanism was dependent on the sample's internal cellular composition and the damage degree of water-holding structures during drying.

4. Conclusions

The results of the study revealed that the drying kinetics of osmotically pretreated coconut meat slice's drying features were strongly influenced by temperature, time, the sucrose solution, and the thickness of the coconut slices. Based on the three important statistical metrics of the models examined (R^2, RMSE, and χ^2), the Asymptotic model was demonstrated to be a more satisfying model for forecasting the drying kinetics of coconut cultivars (SGD × VTT, TGD, and CAT). The osmotic pre-treatment and temperature significantly affected the vitamin C content of coconut meat slices. Consequently, the lyophilized drying condition influenced coconut meat slices maximum vitamin C retention compared to oven drying condition. Depending on factors like the drying medium's temperature and air velocity, lyophilization required more time and energy consumption than convective oven drying. The temperature had a profound effect on the sample's effective moisture diffusivity (D_{eff}). Also, higher temperatures had a significant and detrimental impact on color which corresponded to a decrease in the L^* value and an increase in a^* value, representing a darker and reddish coconut meat slice. Temperature had a significant impact on differences in coconut meat slice rehydration ratio. Osmotic pretreatment of coconut meat slices before drying is recommended for a reduced energy consumption, vitamin C preservation, and improved color

Fig. 4. Relationship between the temperatures (80 °C, 90 °C, 100 °C, and 110 °C) of the dried grated coconut meat slices color. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

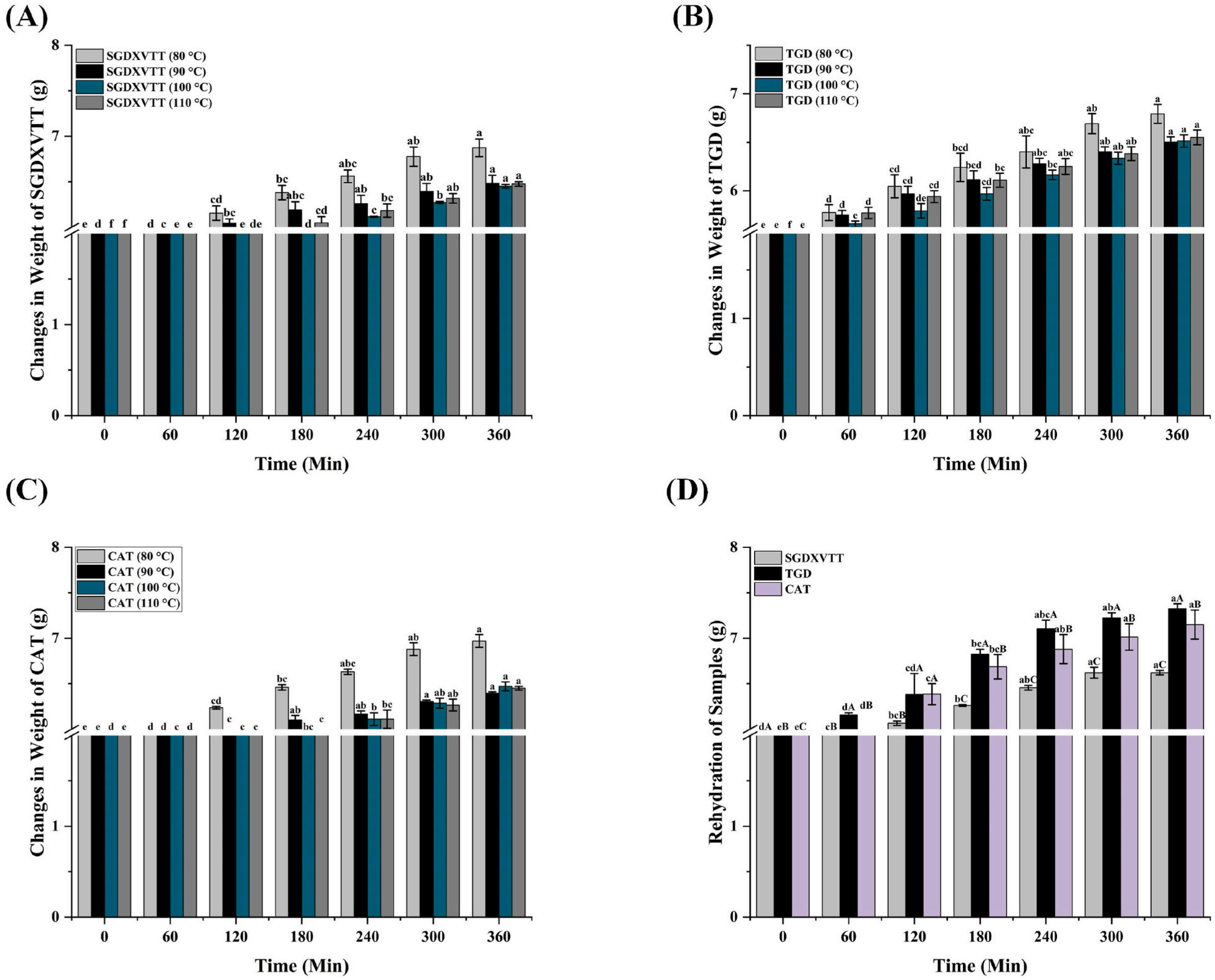

Fig. 5. Rehydration of osmotically dehydrated coconut meat slices. **(A)** Rehydrated oven-dried SGD × VTT; **(B)** Rehydrated oven-dried TGD; **(C)** Rehydrated oven-dried CAT; **(D)** Lyophilized samples. TGD: Tacunan Green Dwarf variety; CAT: Catigan variety; SGD × VTT: Sri-Lanka Green Dwarf × Vanuatu Tall cross breed. Values are means ± SE (n = 3). $^{a\text{-}c}$ Mean values are significantly different ($p < 0.05$) across the treatments, whiles $^{A-D}$ means values are significantly different ($p < 0.05$). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

quality. Also, drying could be a suitable preservation method for coconut meat to mitigate postharvest losses and broaden the selection of coconut meat products. However, further studies of osmotic dehydration at different immersion times and concentrations synergistic impact on coconut meat slices is highly recommended to reveal their clearer functionality of the osmotic solution concentration gradient and effect on final product quality. Also, future research on microbial safety of dried osmosed coconut meat slices on shelf-life quality is recommended.

CRediT authorship contribution statement

Daniel Kwabena Fordjour: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Frederick Sarpong:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Formal analysis, Data curation. **James Owusu-Kwarteng:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Conceptualization. **Evans Frimpong Boateng:** Writing – review & editing, Visualization, Validation, Investigation.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Data availability

Data will be made available on request.

List of symbols

R^2	Determination coefficient
RMSE	Root means square error
χ^2	Reduced Chi-square
D_{eff}	Effective moisture diffusivity
k; a; b; n and c	Kinetic constants
d.b	Dry base
L^*	Lightness
a^*	Redness
b^*	Yellowness
ΔE	Change in color difference
RR	Rehydration ratio
h	Hour
MR	Moisture ratio
WL	Water content loss
SG	Solute gain
WR	Weight loss
SGG × VTT	Sri Lanka Green Dwarf × Vanuatu Tall
CAT	Catigan
TGD	Tacunan Green Dwarf

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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