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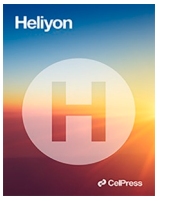

Research article

Convective drying of *Gardenia erubescens* fruits: Effect of pretreatment, slice thickness and drying air temperature on drying kinetics and product quality

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ABSTRACT

Gardenia erubescens fruits are regarded as nutrient-dense, capable of promoting nutritional and metabolic human health. However, they are seasonal and highly perishable which limits their consumption and wider utilization. In this study, the effect of slice thickness (3 mm and 5 mm), pretreatments (steam blanching and dipping in ascorbic acid solution) and drying air temperature (40 °C, 50 °C, 60 °C and 70 °C) on drying kinetics, color, β-carotene and vitamin C content of *Gardenia erubescens* fruits were investigated. The results showed that the drying time increased as slice thickness increased, and decreased as drying air temperature increased but did not follow any trend for pretreatment. The Page model (R^2 values of 0.9998–0.9999) exhibited the best fit to the drying kinetics data. The diffusivity values (5.31×10^{-11} to 4.14×10^{-10} m^2s^{-1}) increased as the slice thickness and drying air temperature increased but had no linear trends with pretreatment. The activation energy ranged from 14.35 to 44.78 $kJmol^{-1}$, with the highest being recorded by 5 mm untreated samples and the lowest by the 3 mm blanched samples. The total color change (ΔE*) of the samples generally decreased as the drying air temperature increased but increased as the slice thickness increased. The ascorbic acid pretreated samples had the least color change, followed by the untreated samples while the blanched samples had the highest change. Overall, the 5 mm ascorbic acid pretreated samples dried at 70 °C had the least color change (13.33 ± 0.52). The blanching and dipping in ascorbic acid solution generally yielded lower β-carotene and vitamin C values as compared to the untreated samples. The 3 mm ascorbic acid pretreated samples dried at 50 °C recorded the lowest β-carotene (42.70 ± 3.21 μg/100 g) while the 5 mm ascorbic acid pretreated samples had the lowest vitamin C (37.50 ± 2.65 mg/100 g) at 70 °C. Pretreatments and drying air temperatures showed mixed effects on the drying characteristics, color, β-carotene and vitamin C contents of fruit slices. The findings, therefore, indicate that a compromise may have to be made on the aforementioned processing conditions in order to meet the desired attributes of one's interest.

1. Introduction

Gardenia erubescens Stapf. & Hutch., a member of the family Rubiaceae is one of the commonest but most neglected fruit shrub

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species of tropical Africa [1]. Mature fruits of the shrub are ellipsoid (3–5 cm long) and pale yellow and are often eaten either raw, roasted or used in sauces and soups [1,2]. The fruits are characterized by significant amounts of fiber, carbohydrates, phenols, β-carotenes, vitamins A, B3 and C and minerals, especially calcium, potassium, iron and zinc [3,4]. As a result, *G. erubescens* fruits have been widely used in herbal medicine to treat obesity, diabetes, gonorrhoea, abdominal/navel pains and sprain [1,5,6]. Despite its significant potential, *G. erubescens* fruits are highly perishable with fast deterioration and therefore require the use of some postharvest treatments to be effectively preserved. Drying is one of these preservation methods [7,8]. Dried fruits have a long shelf-life and therefore can provide a good alternative to fresh fruits, thus allowing out-of-season fruits to be available [9].

Drying involves the reduction of biologically active or free water to a level that is unfavourable to deteriorative chemical reactions and microbial activities, helping to extend the shelf life of the dried products [9,10]. Drying further substantially reduces weight and volume, helping to minimize packaging, storage and transportation costs [8]. Drying air temperature has been shown to have a direct influence on drying kinetics and effective moisture diffusivity where higher temperatures result in higher drying rates and vice versa [11–13]. However, heat-sensitive nutrients such as vitamin C and carotenoids volatilize or degrade at relatively higher temperatures and prolonged drying times [14,15]. Therefore, drying must be carried out under the right conditions in other to extend the shelf life of biological products while retaining their nutritional value. The application of widely used and approved drying systems with wide temperature ranges such as hot-air cabinet dryers plays a crucial role in retaining product quality. According to previous studies, the primary benefits of convective hot air-drying technique are enhanced surface water removal, low operational cost as well as hygienic dried products that can have a long shelf-life of at least a year [16–18]. Just as drying air temperature, the slice thickness of biological products being dried is equally important as it affects moisture diffusivity, activation energy and consequently the drying length of the samples [7,12], and hence has direct or indirect implications on the quality of the dried product. This is because slice thickness is a measure of exposed surface area to drying conditions where the thinner thicknesses indicate the more exposed surface area to the drying conditions, resulting in faster drying and vice versa [19]. Nonetheless, increasing surface area by size reduction for drying purposes does not explicitly guarantee product quality as no clear correlations have been established between them [20,21], hence a need for varying slice thickness of perishable agricultural produce for better quality retention.

In minimizing the adverse effects of drying on quality attributes (e.g. nutritional and color) of food products, pretreatments such as blanching and dipping in solutions of food-grade chemicals like ascorbic acid, and citric acid, among others have been widely used in the food industry and homes [22,23]. A recent study by Korese & Achaglinkame [24] has reported the effect of pretreatment and drying air temperature on proximate and mineral compositions, and functional and pasting properties of *G. erubescens* fruit slices. In a different study, Korese et al. [25] also established the possibility of storing dried slices and powders of the fruits under room conditions using different kinds of polyethylene bags and laminated paper. Though this high-value fruit is gradually receiving research attention, more is still needed to improve the wealth of knowledge about it. As far as drying kinetics, moisture diffusivity, activation energy and influence of drying on color and sensitive nutrients such as β-carotene and vitamin C contents of *G. erubescens* fruit are concerned, there is a paucity of information. These parameters are very important for understanding the behavior of fruit during drying and the amount of heat-sensitive nutrients exemplified above that is retained after the drying process. Furthermore, experimental drying kinetics curve and the curves predicted by mathematical models are specific to each type of agricultural material. Therefore, making known and available the aforementioned information about *G. erubescens* fruit can be a great addition to literature and very useful to researchers and industry players. Thus, this present study aimed at investigating the effect of slice thickness, pretreatment, and drying air temperature on the drying kinetics, effective moisture diffusivity, activation energy, color, β-carotene and vitamin C of *G. erubescens* Stapf. & Hutch. fruit.

Fig. 1. Pictorial view of the bench top cabinet dryer.

2. Materials and methods

2.1. Raw material and pretreatments

Fruit samples of *G. erubescens* (25 kg) were purchased from a local market in Wiaga, located in the Builsa-North Municipal of the Upper East region, Ghana. The fruits were transported to the laboratory and were processed according to the procedure described previously by Korese & Achaglinkame [24] and Korese et al. [25]. The average initial moisture content of fresh samples was 85.80 ± 0.59 % (wet basis, w.b.). Using an electric slicer (Ritterwerk, E16, Germany), the fruits were sliced into 3 mm and 5 mm thicknesses, with a mean length of 36.03 ± 2.98 mm and a width of 11.33 ± 1.72 mm for each slice thickness. These slice thicknesses were selected based on our earlier study [24]. The samples of each slice thickness were thoroughly mixed and then apportioned (4 kg each) into three different pretreatment options: no treatment (untreated), steam blanching at 100 °C for 3 min and dipping in 2% w/v ascorbic acid solution for 3 min [24].

2.2. Drying of G. erubescens fruit slices

Drying experiments were carried out using a bench top laboratory cabinet dryer ''Hohenheim HT mini'' (Innotech-ingenieursgesellschaft mbH, Altdorf, Germany) (Fig. 1) at four different drying air temperatures (40, 50, 60 and 70 °C) with fixed airflow which was set to a constant voltage of 24 V [26,27]. The selected drying air temperatures were based on a range of temperatures used for drying fruits and vegetables [28–30]. To achieve steady-state conditions, the drying system was run for at least 30 min. About 300 g of untreated and pretreated *G. erubescens* fruit slices were placed in the drying chamber perforated tray and allowed to dry. A weighing scale (model PCB 10000-1, KERN and SOHN GmbH, Germany) with an accuracy of ±0.001 g was used to assess the change in weight of the sample during the drying process at 15 min intervals. The drying process was stopped when there were no noticeable changes in the weight of the sample for the last three data points, which indicated that an equilibrium had been reached [31]. After drying, samples were cooled immediately and packed in low-density polyethylene (LDPE) bags and heat-sealed for further analysis. All drying experiments were carried out in triplicate, and averages are reported.

The moisture ratio (MR) and drying rate (DR) under drying conditions of *G. erubescens* fruit slices were calculated using Eqs. (1) and (2) [13].

$$MR = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{2}$$

where M_t is the dry basis moisture content (g water/g dry mass) at time t, M_0 is the initial moisture content (g water/g dry mass) and M_e is the equilibrium moisture content (g water/g dry mass). According to some researchers, the value of M_e is relatively small compared to M_t or M_0. Therefore, M_e was set to zero [13].

2.3. Mathematical modeling of the drying curves

Due to the absence of information in the literature on modeling of the drying behavior of *G. erubescens* fruit slices, several models including simple and complex ones need to be tested to find a suitable model for predicting the drying behavior of the fruit. Hence, six (6) thin-layer regularly used drying models were selected to fit the experimental data (Eqs. (3)–(8)). Model parameters were estimated using non-linear regression generalized reduced gradient model fitting in Excel (2016) Solver software procedure. The coefficient of determination (R^2) and root mean square error (RMSE) were used to select the model that best described the drying curve and the determination of the goodness of fit [32,33]. These statistical parameters were calculated based on formulae available in literature [32,34]. Generally, the model with the highest R^2 and lowest RMSE values is considered the best model [35,36].

$$\text{Page} : MR = \exp(-kt^n) \tag{3}$$

$$\text{Diffusionapproach} : MR = a\exp(-kt) + (1-a)\exp(-kbt) \tag{4}$$

$$\text{Wang and Singh} : MR = 1 + at + bt^2 \tag{5}$$

$$\text{HendersonandPabis} : MR = a\exp(-kt) \tag{6}$$

$$\text{Logarithmic} : MR = a\exp(-kt) + c \tag{7}$$

$$\text{Newton} : MR = \exp(-kt) \tag{8}$$

where a, b, c, k and n are drying constants while t is the drying time.

2.4. Effective moisture diffusivity

For thin-layer drying, the drying data in the falling rate period are usually analyzed using Fick's equation of diffusion [37]. Assuming that the coefficient of diffusion of the drying process of the *G. erubescens* fruit slices is constant, with negligible shrinkage and uniform initial moisture concentration, change in moisture is driven by diffusion and the samples are assumed as an infinite slab geometry [38]. The effective moisture diffusivity (D_{eff}) can then be calculated using Fick's second equation of diffusion (Eq. (9)).

$$MR = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-\frac{(2n+1)^2\pi^2 D_{eff}t}{4L^2}\right) \tag{9}$$

where MR is the dimensionless moisture ratio, n is a positive integer, L is the half-thickness (m) of the slab in the samples, D_{eff} is the effective moisture diffusivity (m^2s^{-1}) and t is the drying time (s). Eq. (9) is simplified taking into consideration only the first term as shown in Eq. (10).

$$MR = \frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}t}{4L^2}\right) \tag{10}$$

The D_{eff} can also be estimated using the slope (Eq. (11)) of Eq. (10), by plotting the natural logarithm (ln) of the MR against the drying time to obtain a straight line with slope *m*. The D_{eff} is then obtained as shown in Eq. (12).

$$m = \frac{\pi^2 D_{eff}}{4L^2} \tag{11}$$

$$D_{eff} = \frac{4mL^2}{\pi^2} \tag{12}$$

2.5. Activation energy

Activation energy is the minimum amount of energy required to commence the drying process under the influence of temperature and D_{eff}. The relationship among the activation energy, the drying temperature and the D_{eff} is described using the Arrhenius-type equation (Eq. (13)).

$$D_{eff} = D_0\exp\left(-\frac{E_a}{R(T+273.15)}\right) \tag{13}$$

where D_0 is the Arrhenius equation pre-exponential factor (m^2s^{-1}), E_a is the activation energy ($kJmol^{-1}$), R is the ideal gas constant ($kJmol^{-1}K^{-1}$) and T is the drying temperature (°C). Plotting ln(D_{eff}) against the reciprocal of the temperature (1/T+273.15), the activation energy was obtained by multiplying the ideal gas constant by the slope (m_1) of the graph (Eq. (14)).

$$m_1 = -\frac{E_a}{R} \tag{14}$$

2.6. Color

A handheld chroma meter (CR-400, Minolta Konica Inc., Osaka, Japan), after being calibrated with a standard white plate at D65 illumination (Y = 80.1, x = 0.3219, y = 0.3394) was used to measure the color, following the procedures of Izli et al. [39]. The lightness (L*) (0 = black, white = 100), redness (a*) (-ve = green, +ve = red) and yellowness (b*) (-ve = blue, +ve = yellow) of the *G. erubescens* slices were directly measured with the chroma meter. Five measurements were performed at random locations for each sample, before drying and after drying. The chroma (C*), hue (h*) and total color change (ΔE*) values of the samples were calculated using the a*, b* and ΔL*(L*-L_o*), Δa*(a*-a_o*) and Δb* (b*-b_o*) values as shown in Eqs. (15)–(17) [31,40,41]. L_o*, a_o* and b_o* represent the values of the fresh *G. erubescens* fruits while L*, a* and b* are the final values of the dried samples.

$$C^* = \left(a^{*2} + b^{*2}\right)^{1/2} \tag{15}$$

$$h = \left\{\begin{array}{c} tan^{-1}(b^*/a^*)\ (when\ a^* > 0) \\ 180^\circ + tan^{-1}(b^*/a^*)\ (when\ a^* < 0) \end{array}\right\} \tag{16}$$

$$\Delta E^* = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2} \tag{17}$$

2.7. Determination of beta-carotene and vitamin C contents

Extracts of the *G. erubescens* fruit samples were obtained following procedures of Mohammed et al. [42] by homogenizing 10 g of each sample in 50 mL of acetic acid solution at 3000 rpm for 15 min using Rotofix 32 A centrifuge (Andreas Hettich GmbH and Co. KG,

Tuttlingen, Germany). The homogenous solution was gently transferred to a 100 mL volumetric flask and diluted with acetic acid solution to the 100 mL mark. The solution was filtered and the filtrate was used for the β-carotene and vitamin C determinations in triplicates.

A 15 μg/mL stock solution of β-carotene was prepared by dissolving 750 μg of standard β-carotene in 50 mL of acetic acid solution. The absorbance of β-carotene was taken using a UV/Vis double beam scanning spectrophotometer (Excellence UV5, Mettler Toledo, Switzerland) at a working spectra range of 350 nm–600 nm and the β-carotene content (μg/100 g) estimated using the standard β-carotene calibration curve [43].

An ascorbic acid stock solution of 500 ppm was prepared by dissolving 0.05 g of crystalline ascorbic acid in 100 mL of acetic acid solution. The vitamin C content (mg/100 g) in the *G. erubescens* samples was determined spectrophotometrically (Excellence UV5, Mettler Toledo, Switzerland) at an absorbance of 280 nm using ascorbic acid standard calibration curve [42].

2.8. Statistical analysis

The results of the quality analysis were analyzed using general linear model in GenStat statistical package (12th edition) with mean separation executed by Tukey post hoc option in the same statistical tool at a 5% significance level. Analyzed data were then presented in tables and graphs.

3. Results and discussion

3.1. Drying kinetics

The impact of the various factors on the drying kinetics of *G. erubescens* fruits has been presented in Fig. 2. A general decline in moisture ratio with an increase in drying time was observed (Fig. 2). It was also observed that the drying time decreased as the drying air temperature increased, due to elevation of heat in the samples as the air temperature increased [44]. At 40 °C, 50 °C, 60 °C and 70 °C, increasing slice thickness from 3 mm to 5 mm resulted in respective increases in drying time by 53 %, 43 %, 33 % and 50 %. These increases in drying time with increased slice thickness were as a result of longer distances for moisture movement to the samples' surface in the 5 mm thick samples as compared to the 3 mm thick samples [45]. Following the same order of drying temperature, increasing slice thickness from 3 mm to 5 mm yielded increments in drying time of about 30 %, 33 %, 23 % and 21 %, and 53 %, 69 %, 70 % and 71 % for the blanched and ascorbic acid-treated samples, respectively. This implies that drying of the 5 mm blanched samples was comparatively faster than of the ascorbic acid treated samples, indicating that the blanched samples required less energy to dry than the ascorbic samples which was subsequently confirmed by the activation energy results (section 3.2). In the application of drying as a preservative technique, interest is not only placed on the dried product but also on the time taken to achieve the desired drying.

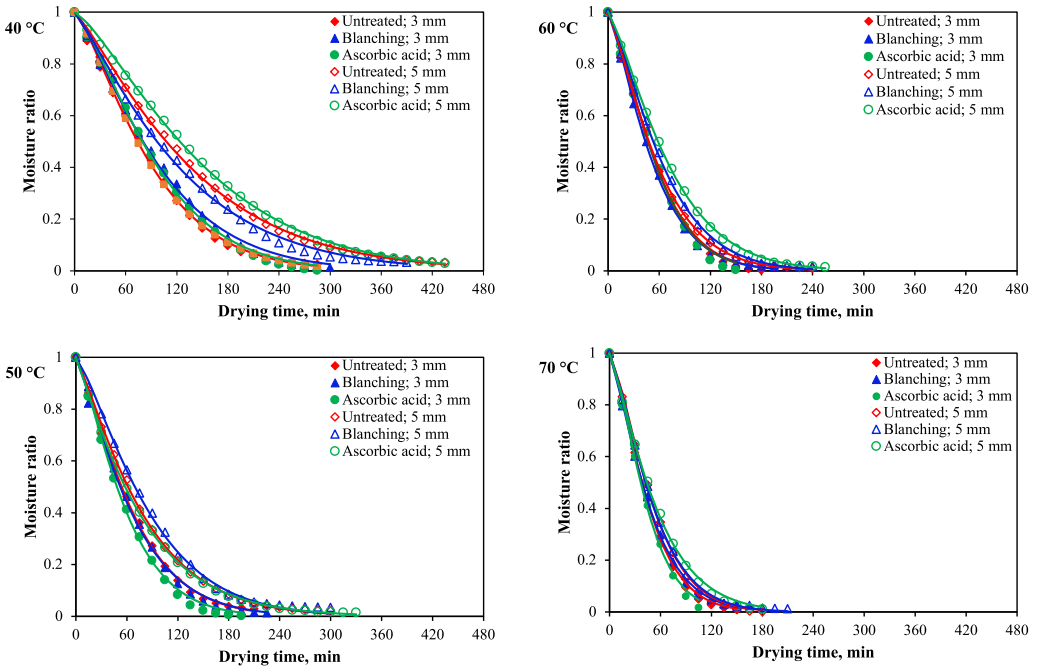

Fig. 2. Changes in moisture ratio of untreated and pretreated *G. erubescens* fruit slices (3 mm and 5 mm) at different temperatures. The solid lines on the moisture ratio curves represent an approximation of the Page model.

Drying time is particularly of great importance because of its direct or indirect link with cost, physical and nutritional quality of biological products. Holding all other conditions supposedly constant, the above percentage margins are likely to be saved should 3 mm thick slices of *G. erubescens* be dried at the aforementioned conditions.

No clear trends could be seen in terms of pretreatment. That notwithstanding, there were some quantifiable differences in drying time among the pretreatments. At 40 °C, the steam-blanched samples took 5 % more time to dry and 12 % less time to dry as compared to the untreated and ascorbic acid-treated samples, both of which had the same drying time for the 3 mm and 5 mm thicknesses, respectively. At 50 °C, the ascorbic acid treatment decreased the drying time by 7 % while the blanching increased it by the same margin (7 %) for the 3 mm samples when compared with the untreated option. However, at the same temperature, the ascorbic acid treatment caused a 10 % prolongation in the drying time relative to the blanching and untreated. Drying the 3 mm samples at 60 °C saw a reduction in the drying time by 17 % for the ascorbic acid treatment and an increase of 8 % for the blanching when both were compared with the untreated option. For the 5 mm samples at 60 °C, an increase of 6 % in drying time was only recorded for the ascorbic acid treatment relative to the other two pretreatment options. Further, the untreated 3 mm samples took 38 % less time to dry as compared to the 3 mm blanched samples but 13% more time than the 3 mm ascorbic acid-treated samples at 70 °C. At the same 70 °C temperature for the 5 mm thickness, both the untreated and ascorbic acid-treated samples recorded 17 % less drying time as compared with the blanched samples. Chin et al. [46] recorded similar trends when different slices of kiwi fruit were dried at similar hot-air drying air temperatures.

These curves did not have any constant rate period but all underwent a falling rate pattern. The rate of drying (Fig. 3) decreased with an increase in the slice thickness and a decrease in the moisture content of the sample under the same pretreatment option and drying air temperature. The drying rates of the 3 mm samples were greatly higher than those of the 5 mm samples of the various pretreatments at the lower temperatures (40 °C and 50 °C). This could be attributed to the difficulty in heat penetration and distribution in the sample to cause the removal of water as the slice thickness increased. However, the variations between the drying rates of these thicknesses were marginal at the higher temperatures (60 °C and 70 °C) which could be attributed to higher heat penetration and distribution as a result of higher heat intensity.

3.2. Effective moisture diffusivity and activation energy

The effective moisture diffusivity and activation energy of the drying process of the *G. erubescens* fruit slices are shown in Table 1. The D_{eff} which measures the ease of moisture movement from the core of the sample to the surface for removal ranged from 5.31×10^{-11} to 4.14×10^{-10} m^2s^{-1} and fell within the 10^{-11} to 10^{-6} m^2s^{-1} range for most food substances [7,8]. Varietal, cellular and morphological disparities, moisture content, as well as the drying method and type of dryer used largely account for the variations in effective moisture diffusivity reported for different agricultural produce [44].

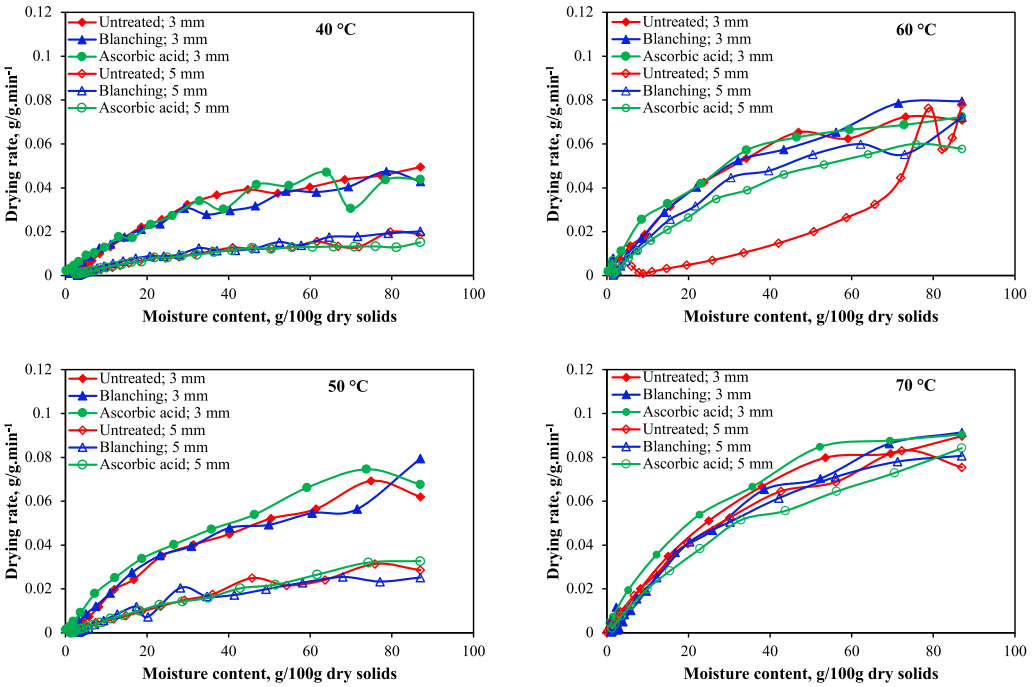

Fig. 3. Drying rate versus moisture content of untreated and pretreated *G. erubescens* fruit slices (3 mm and 5 mm) at different temperatures (40, 50, 60 and 70 °C).

Table 1
Effective moisture diffusivity and activation energy of drying of *G. erubescen* fruit samples.

Slice thickness (mm)	Pretreatment	Temperature (°C)	Effective moisture diffusivity (m^2s^{-1})	Coefficient of determination (R^2)	Activation energy ($kJmol^{-1}$)	Coefficient of determination (R^2)
3	Untreated	40	5.31×10^{-11}	0.9911	26.88	0.9244
		50	7.03×10^{-11}	0.9905		
		60	1.18×10^{-10}	0.9520		
		70	1.21×10^{-10}	0.9820		
	Blanching	40	5.78×10^{-11}	0.9734	14.35	0.8900
		50	7.90×10^{-11}	0.9877		
		60	9.01×10^{-11}	0.9811		
		70	9.41×10^{-11}	0.9833		
	Ascorbic acid	40	7.13×10^{-11}	0.9132	19.05	0.8317
		50	1.18×10^{-10}	0.9438		
		60	1.28×10^{-10}	0.9048		
		70	1.40×10^{-10}	0.9206		
5	Untreated	40	8.88×10^{-11}	0.9957	44.78	0.9880
		50	1.46×10^{-10}	0.9948		
		60	2.19×10^{-10}	0.9951		
		70	4.14×10^{-10}	0.9231		
	Blanching	40	1.03×10^{-10}	0.9885	27.97	0.9916
		50	1.36×10^{-10}	0.9775		
		60	2.03×10^{-10}	0.9839		
		70	2.55×10^{-10}	0.9777		
	Ascorbic acid	40	9.09×10^{-11}	0.9897	32.38	0.9885
		50	1.48×10^{-10}	0.9919		
		60	1.91×10^{-10}	0.9904		
		70	2.79×10^{-10}	0.9806		

The diffusivity values increased as the slice thickness and drying air temperature increased which corroborated the trends reported by Dinrifo [7] and Oyefeso & Raji [12] for similar slice thicknesses of tannia cormels and sweet potato dried at similar air temperatures, respectively. The observed trend in relation to the slice thickness could be attributed to higher moisture concentration in the core of the 5 mm thick slices than the 3 mm slices while that in terms of temperature could be explained by increased heat intensity as the temperature increased which enhanced the activity of water molecules resulting in higher diffusivity [11]. Mixed trends were observed for the D_{eff} in terms of the pretreatment options. For instance, the untreated samples recorded lower values than pretreated samples at 40 °C and 50 °C, the second highest values after the ascorbic acid treated samples for the 3 mm thickness and the highest for the 5 mm thickness at the 60 °C and 70 °C drying temperatures. These mixed trends partly explain the trend of drying time recorded above in relation to pretreatment. Similar trends were also reported by Dinrifo [7] for sweet potato slices blanching, dipping in sodium metabisulfite and control (no treatment). Co-efficient of determination values of 0.9520–0.9957 were obtained which described a high prediction accuracy for the moisture diffusivity of the *G. erubescens* fruit slices using Fick's second law equation.

The E_a ranged from 14.35 to 44.78 $kJmol^{-1}$ which was within the 12.7 to 110 $kJmol^{-1}$ for food and agricultural produce [12]. The values increased with an increase in the slice thickness of the samples, indicating that higher energy was needed to initiate the drying of the 5 mm slices than was required for the 3 mm slices. These trends agreed with those reported in similar works [7,12]. The drying of the pretreated samples recorded lower E_a values than that of the untreated samples, with the blanched samples recording the lowest values. This suggested that the steam blanching and dipping in the ascorbic acid solution reduced the energy needed for the diffusion of moisture to the surface of the samples for evaporation as a result of a possible reduction in intermolecular bond strength. Similar findings with similar attributable reasons were reported elsewhere [7,12,47,48]. The R^2 range of 0.8317–0.9916 is a confirmation of the suitability of the Arrhenius-type equation in predicting the activation energy of the *G. erubescens* fruit slices under similar slice thickness, pretreatment and drying air temperature.

3.3. Evaluation of drying models

The statistical parameters, RMSE and R^2 of the models used are presented in Table 2. Generally, the RMSE values for all the models ranged from 0.0001 to 0.0570 while R^2 values ranged from 0.9763 to 0.9999. The RMSE ranges of 0.0001–0.0063, 0.0045–0.0190, 0.0043–0.0156, 0.0162–0.0523, 0.0031–0.0181 and 0.0189–0.0570 were observed for the Page, Diffusion Approach, Wang and Singh, Henderson and Pabis, Logarithmic and Newton models, respectively. Following the same order of presentation of the models, R^2 values of 0.9998–0.9999, 0.9966–0.9997, 0.9974–0.9998, 0.9763–0.9971, 0.9961–0.9999 and 0.9800–0.9978 were respectively obtained. Based on the goodness of fit and prediction precision criteria of lowest RMSE value and highest R^2 value, the Page model was found to have the best fitting for the drying moisture data of the *G. erubescens* fruits since it recorded relatively the lowest RMSE and the highest R^2. Thus, the Page model could give better a prediction of the drying behavior of *G. erubescens* fruits under similar conditions in future works than any of the models used. The Page model was also adjudged the best for predicting thin-layer drying of Crabapple slices (3 mm and 5 mm) [49] and hawthorn fruit slice (10 mm) [50].

Table 2
Statistical results obtained from different thin-layer drying models of *G. erubescens* fruit slices.

Model name	Slice thickness, mm	Treatment	Constants	RMSE	R^2
40 °C					
Page	3	Untreated	k = 0.0026; n = 1.3005	0.0022	0.9999
		Blanched	k = 0.0027; n = 1.2655	0.0016	0.9999
		Ascorbic acid	k = 0.0019; n = 1.3481	0.0024	0.9998
	5	Untreated	k = 0.0026; n = 1.1925	0.0032	0.9998
		Blanched	k = 0.0031; n = 1.1825	0.0051	0.9999
		Ascorbic acid	k = 0.0013; n = 1.3057	0.0031	0.9999
Diffusion approach	3	Untreated	a = 9.1820; b = 1.0893; k = 0.0183	0.0141	0.9977
		Blanched	a = 6.5169; b = 1.1202; k = 0.0158	0.0143	0.9980
		Ascorbic acid	a = 7.0855; b = 1.1287; k = 0.0175	0.0137	0.9978
	5	Untreated	a = 6.5458; b = 1.1057; k = 0.0111	0.0104	0.9987
		Blanched	a = 6.6084; b = 1.1019; k = 0.0122	0.0115	0.9983
		Ascorbic acid	a = 7.9154; b = 1.1071; k = 0.0110	0.0106	0.9987
Wang and Singh	3	Untreated	a = −0.0076; b = 0.000014	0.0082	0.9992
		Blanched	a = −0.0070; b = 0.000012	0.0052	0.9997
		Ascorbic acid	a = −0.0070; b = 0.000011	0.0127	0.9981
	5	Untreated	a = −0.0051; b = 0.000007	0.0125	0.9992
		Steam blanched	a = −0.0057; b = 0.000008	0.0106	0.9995
		Ascorbic acid	a = −0.0044; b = 0.000004	0.0147	0.9979
Henderson and Pabis	3	Untreated	a = 1.0551; k = 0.0108	0.0382	0.9841
		Blanched	a = 1.0469; k = 0.0096	0.0348	0.9878
		Ascorbic acid	a = 1.0627; k = 0.0101	0.0415	0.9806
	5	Untreated	a = 1.0411; k = 0.0072	0.0267	0.9915
		Blanched	a = 1.0381; k = 0.0079	0.0257	0.9918
		Ascorbic acid	a = 1.0664; k = 0.0065	0.0362	0.9849
Logarithmic	3	Untreated	a = 1.4502; c = −0.4400; k = 0.0057	0.0109	0.9986
		Blanched	a = 1.4849; c = −0.4791; k = 0.0050	0.0063	0.9998
		Ascorbic acid	a = 1.6162; c = −0.6018; k = 0.0047	0.0136	0.9978
	5	Untreated	a = 1.2401; c = −0.2358; k = 0.0048	0.0087	0.9990
		Blanched	a = 1.2901; c = −0.2889; k = 0.0050	0.0031	0.9999
		Ascorbic acid	a = 1.4323; c = −0.4152; k = 0.0036	0.0113	0.9984
Newton	3	Untreated	k = 0.0102	0.0440	0.9874
		Blanched	k = 0.0093	0.0401	0.9895
		Ascorbic acid	k = 0.0094	0.0485	0.9845
	5	Untreated	k = 0.0068	0.0307	0.9933
		Blanched	k = 0.0076	0.0296	0.9935
		Ascorbic acid	k = 0.0061	0.0439	0.9887
50 °C					
Page	3	Untreated	k = 0.0044; n = 1.2678	0.0039	0.9998
		Blanched	k = 0.0054; n = 1.2265	0.0020	0.9999
		Ascorbic acid	k = 0.0045; n = 1.3005	0.0058	0.9998
	5	Untreated	k = 0.0054; n = 1.1814	0.0063	0.9999
		Blanched	k = 0.0031; n = 1.2792	0.0021	0.9999
		Ascorbic acid	k = 0.0074; n = 1.1187	0.0038	0.9998
Diffusion approach	3	Untreated	a = 5.7451; b = 1.1454; k = 0.0239	0.0099	0.9989
		Blanched	a = 9.2510; b = 1.0763; k = 0.0240	0.0176	0.9966
		Ascorbic acid	a = 5.6930; b = 1.1556; k = 0.0274	0.0116	0.9986
	5	Untreated	a = 2.7234; b = 1.3157; k = 0.0179	0.0055	0.9996
		Blanched	a = 5.3829; b = 1.1601; k = 0.0186	0.0119	0.9983
		Ascorbic acid	a = 4.2499; b = 1.1374; k = 0.0181	0.0045	0.9997
Wang and Singh	3	Untreated	a = −0.0106; b = 0.000029	0.0057	0.9997
		Blanched	a = −0.0108; b = 0.000030	0.0079	0.9995
		Ascorbic acid	a = −0.0117; b = 0.000034	0.0069	0.9995
	5	Untreated	a = −0.0093; b = 0.000024	0.0090	0.9993
		Blanched	a = −0.0080; b = 0.000015	0.0105	0.9988
		Ascorbic acid	a = −0.0098; b = 0.000027	0.0108	0.9992
Henderson and Pabis	3	Untreated	a = 1.0480; k = 0.0147	0.0338	0.9881
		Blanched	a = 1.0339; k = 0.0148	0.0346	0.9874
		Ascorbic acid	a = 1.0501; k = 0.0165	0.0379	0.9857
	5	Untreated	a = 1.0389; k = 0.0125	0.0228	0.9942
		Blanched	a = 1.0524; k = 0.0114	0.0349	0.9863
		Ascorbic acid	a = 1.0255; k = 0.0128	0.0162	0.9971
Logarithmic	3	Control	a = 1.3399; c = −0.3273; k = 0.0088	0.0088	0.9991
		Blanched	a = 1.3414; c = −0.3445; k = 0.0086	0.0077	0.9993
		Ascorbic acid	a = 1.4002; c = −0.3872; k = 0.0093	0.0089	0.9991
	5	Control	a = 1.1694; c = −0.1545; k = 0.0094	0.0120	0.9985
		Blanched	a = 1.4208; c = −0.4088; k = 0.0063	0.0104	0.9987
		Ascorbic acid	a = 1.1168; c = −0.1108; k = 0.0103	0.0037	0.9998

(*continued on next page*)

Table 2 (*continued*)

Model name	Slice thickness, mm	Treatment	Constants	RMSE	R^2
Newton	3	Control	k = 0.0139	0.0391	0.9906
		Blanched	k = 0.0143	0.0372	0.9893
		Ascorbic acid	k = 0.0157	0.0433	0.9886
	5	Control	k = 0.0120	0.0274	0.9955
		Blanched	k = 0.0107	0.0407	0.9892
		Ascorbic acid	k = 0.0125	0.0189	0.9978
60 °C					
Page	3	Untreated	k = 0.0037; n = 1.3627	0.0037	0.9998
		Blanched	k = 0.0054; n = 1.2882	0.0012	0.9998
		Ascorbic acid	k = 0.0034; n = 1.3841	0.0005	0.9998
	5	Untreated	k = 0.0053; n = 1.2607	0.0002	0.9999
		Blanched	k = 0.0040; n = 1.2990	0.0008	0.9999
		Ascorbic acid	k = 0.0037; n = 1.2832	0.0022	0.9999
Diffusion approach	3	Untreated	a = 7.3226; b = 1.1264; k = 0.0300	0.0153	0.9975
		Blanched	a = 6.9949; b = 1.1188; k = 0.0303	0.0132	0.9982
		Ascorbic acid	a = 8.0478; b = 1.1158; k = 0.0307	0.0176	0.9968
	5	Untreated	a = 4.5805; b = 1.1896; k = 0.0264	0.0135	0.9980
		Blanched	a = 8.1902; b = 1.1009; k = 0.0254	0.0148	0.9977
		Ascorbic acid	a = 5.8087; b = 1.1478; k = 0.0223	0.0087	0.9992
Wang and Singh	3	Untreated	a = −0.0118; b = 0.000030	0.0090	0.9992
		Blanched	a = −0.0130; b = 0.000041	0.0043	0.9998
		Ascorbic acid	a = −0.0117; b = 0.000029	0.0092	0.9991
	5	Untreated	a = −0.0120; b = 0.000038	0.0156	0.9974
		Blanched	a = −0.0106; b = 0.000027	0.0096	0.9991
		Ascorbic acid	a = −0.0096; b = 0.000023	0.0092	0.9992
Henderson and Pabis	3	Untreated	a = 1.0513; k = 0.0170	0.0446	0.9795
		Blanched	a = 1.0424; k = 0.0180	0.0375	0.9858
		Ascorbic acid	a = 1.0529; k = 0.0172	0.0476	0.9772
	5	Untreated	a = 1.0418; k = 0.0164	0.0349	0.9872
		Blanched	a = 1.0479; k = 0.0151	0.0395	0.9844
		Ascorbic acid	a = 1.0529; k = 0.0136	0.0351	0.9874
Logarithmic	3	Untreated	a = 1.6992; c = −0.6893; k = 0.0074	0.0103	0.9988
		Blanched	a = 1.4351; c = −0.4278; k = 0.0098	0.0071	0.9994
		Ascorbic acid	a = 1.7714; c = −0.7632; k = 0.0070	0.0105	0.9988
	5	Untreated	a = 1.2838; c = −0.2714; k = 0.0106	0.0187	0.9961
		Blanched	a = 1.3872; c = −0.3788; k = 0.0085	0.0120	0.9984
		Ascorbic acid	a = 1.3297; c = −0.3139; k = 0.0083	0.0109	0.9987
Newton	3	Untreated	k = 0.0161	0.0499	0.9829
		Blanched	k = 0.0172	0.0417	0.9882
		Ascorbic acid	k = 0.0163	0.0528	0.9809
	5	Untreated	k = 0.0157	0.0390	0.9892
		Blanched	k = 0.0144	0.0441	0.9872
		Ascorbic acid	k = 0.0129	0.0409	0.9902
70 °C					
Page	3	Untreated	k = 0.0050; n = 1.3513	0.0001	0.9999
		Blanched	k = 0.0066; n = 1.2752	0.0010	0.9999
		Ascorbic acid	k = 0.0042; n = 1.4148	0.0025	0.9998
	5	Untreated	k = 0.0041; n = 1.3650	0.0018	0.9999
		Blanched	k = 0.0049; n = 1.3243	0.0021	0.9999
		Ascorbic acid	k = 0.0064; n = 1.2366	0.0017	0.9998
Diffusion approach	3	Untreated	a = 6.8185; b = 1.1350; k = 0.0363	0.0146	0.9979
		Blanched	a = 5.4884; b = 1.1547; k = 0.0336	0.0110	0.9987
		Ascorbic acid	a = 7.9699; b = 1.1226; k = 0.0401	0.0190	0.9968
	5	Untreated	a = 7.6335; b = 1.1217; k = 0.0332	0.0139	0.9981
		Blanched	a = 6.9024; b = 1.1282; k = 0.0322	0.0132	0.9983
		Ascorbic acid	a = 6.2587; b = 1.1224; k = 0.0284	0.0118	0.9984
Wang and Singh	3	Untreated	a = −0.0145; b = 0.000048	0.0092	0.9992
		Blanched	a = −0.0149; b = 0.000055	0.0043	0.9998
		Ascorbic acid	a = −0.0152; b = 0.000052	0.0103	0.9991
	5	Untreated	a = −0.0130; b = 0.000039	0.0110	0.9989
		Blanched	a = −0.0132; b = 0.000042	0.0081	0.9994
		Ascorbic acid	a = −0.0128; b = 0.000041	0.0049	0.9998
Henderson and Pabis	3	Untreated	a = 1.0447; k = 0.0209	0.0444	0.9812
		Blanched	a = 1.0367; k = 0.0203	0.0355	0.9872
		Ascorbic acid	a = 1.0514; k = 0.0224	0.0523	0.9763
	5	Untreated	a = 1.0534; k = 0.0190	0.0454	0.9808
		Blanched	a = 1.0472; k = 0.0189	0.0414	0.9836
		Ascorbic acid	a = 1.0343; k = 0.0175	0.0320	0.9891

(*continued on next page*)

Table 2 (*continued*)

Model name	Slice thickness, mm	Treatment	Constants	RMSE	R^2
Logarithmic	3	Untreated	a = 1.5510; c = −0.5423; k = 0.0101	0.0111	0.9987
		Blanched	a = 1.4157; c = −0.4095; k = 0.0113	0.0072	0.9994
		Ascorbic acid	a = 1.6022; c = −0.5908; k = 0.0103	0.0127	0.9985
	5	Untreated	a = 1.4951; c = −0.4808; k = 0.0097	0.0127	0.9984
		Blanched	a = 1.4367; c = −0.4260; k = 0.0102	0.0105	0.9989
		Ascorbic acid	a = 1.3656; c = −0.3623; k = 0.0102	0.0055	0.9997
Newton	3	Untreated	k = 0.0199	0.0486	0.9841
		Blanched	k = 0.0195	0.0391	0.9892
		Ascorbic acid	k = 0.0213	0.0570	0.9800
	5	Untreated	k = 0.0180	0.0508	0.9843
		Blanched	k = 0.0180	0.0460	0.9865
		Ascorbic acid	k = 0.0168	0.0352	0.9908

Where a, b, c, k and n are empirical constants and coefficients in drying models.

3.4. Color

Color is arguably the first quality parameter that draws consumers' attention to food products and hence is given critical attention during processing. It is by far the physical indicator of the type of nutrients present in food products [51]. The impact of the various treatments on the color properties of the fruits is illustrated in Table 3. The dried samples were generally less bright, more reddish and more yellowish than the fresh sample due to the degradation of some color pigments like chlorophylls and the revelation of red and yellow pigments as impacted by the heating process. The L* attribute of color was significantly ($p < 0.001$) influenced by the various

Table 3
Effect of drying air temperature, slice thickness and pretreatments of color properties, β-carotene and vitamin C contents of *G. erubescens* fruit samples.

			L*	a*	b*	C*	h*	ΔE*	β-carotene (μg/100 g)	Vitamin C (mg/100 g)
			Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Fresh *G. erubescens* fruit			73.34±0.04	-6.64±0.05	36.29±0.08	36.89±0.08	100.37±0.06	-	691.95±12.20	25.92±0.19
Dried *G. erubescens* fruit										
Temp. (°C)	Slice thickness (mm)	Pretreatment								
40	3	Untreated	43.52±0.32^{a}	8.54±0.06^{e}	27.62±0.34^{a}	28.91±0.34^{a}	255.66±1.78^{c}	34.56±0.34^{a}	255.66±1.78^{c}	319.50±6.08^{a}
		Blanched	52.37±1.37^{de}	6.08±0.44^{e}	49.19±0.50^{a}	49.56±0.54^{lm}	116.77±3.81^{j}	27.73±1.05^{e}	116.77±3.81^{j}	286.50±4.36^{c}
		Ascorbic acid	62.77±0.91^{i}	6.72±0.43^{e}	39.60±0.48^{hi}	40.17±0.49^{gh}	401.24±7.60^{d}	17.37±0.66^{i}	401.24±7.60^{d}	47.17±2.08^{h}
	5	Untreated	43.72±0.12^{a}	9.01±0.10^{ef}	28.25±0.34^{a}	29.65±0.32^{a}	538.07±0.89^{b}	34.45±0.17^{a}	538.07±0.89^{b}	288.17±4.04^{bc}
		Blanched	48.04±0.45^{b}	8.31±0.08^{de}	37.80±0.18^{fg}	38.70±0.18^{ef}	233.03±6.59^{f}	29.43±0.35^{cd}	233.03±6.59^{f}	265.50±7.00^{d}
		Ascorbic acid	52.74±0.13^{de}	16.90±0.08^{j}	35.31±0.16^{d}	39.14±0.13^{fg}	140.69±1.18^{i}	31.30±0.09^{b}	140.69±1.18^{i}	43.50±1.73^{h}
50	3	Untreated	53.76±0.90^{e}	7.56±0.48^{d}	33.27±0.10^{c}	34.12±0.17^{c}	205.50±4.52^{g}	24.38±0.70^{g}	205.50±4.52^{g}	298.50±1.00^{bc}
		Blanched	51.30±1.13^{cd}	8.97±0.09^{ef}	49.33±0.64^{n}	50.14±0.64^{m}	200.87±6.92^{g}	30.01±0.67^{c}	200.87±6.92^{g}	295.17±7.37^{bc}
		Ascorbic acid	60.87±0.35^{h}	9.66±0.37^{fg}	41.65±0.33^{jk}	42.75±0.35^{i}	42.70±3.21^{l}	21.21±0.35^{jk}	42.70±3.21^{l}	63.83±5.69^{g}
	5	Untreated	50.77±0.15^{c}	8.65±0.10^{e}	29.77±0.15^{b}	31.00±0.11^{b}	398.41±3.12^{d}	28.03±0.14^{e}	398.41±3.12^{d}	246.50±3.00^{ef}
		Blanched	55.53±0.05^{f}	8.94±0.12^{ef}	51.07±0.08^{o}	51.85±0.07^{n}	208.08±4.71^{g}	27.90±0.05^{e}	208.08±4.71^{g}	259.83±6.81^{de}
		Ascorbic acid	57.34±0.13^{g}	10.44±0.05^{gh}	42.15±0.15^{k}	43.42±0.14^{i}	167.44±2.04^{h}	24.14±0.85^{g}	167.44±2.04^{h}	38.17±2.89^{h}
60	3	Untreated	55.50±0.59^{f}	4.94±0.12^{b}	33.00±0.29^{c}	33.37±0.29^{c}	84.11±2.04^{k}	21.52±0.48^{ij}	84.11±2.04^{k}	286.83±2.08^{c}
		Blanched	49.03±0.03^{b}	7.61±0.11^{d}	40.73±0.27^{ij}	41.43±0.24^{h}	397.38±5.83^{d}	28.53±0.03^{de}	397.38±5.83^{d}	297.83±7.37^{bc}
		Ascorbic acid	64.00±0.18^{ij}	10.39±0.06^{gh}	46.09±0.13^{m}	47.25±0.12^{k}	52.21±1.18^{l}	21.76±0.04^{hij}	52.21±1.18^{l}	75.50±5.57^{g}
	5	Untreated	57.09±0.03^{g}	8.23±0.09^{de}	42.57±0.17^{k}	43.35±0.15^{i}	451.65±4.45^{c}	22.91±0.05^{h}	451.65±4.45^{c}	246.17±3.06^{ef}
		Blanched	50.69±0.05^{c}	8.64±0.11^{e}	44.21±0.34^{l}	45.05±0.36^{j}	264.40±5.47^{e}	28.44±0.11^{de}	264.40±5.47^{e}	270.17±2.52^{d}
		Ascorbic acid	63.22±0.15^{i}	10.62±0.06^{hi}	47.11±0.26^{m}	48.29±0.26^{kl}	555.30±3.12^{a}	22.74±0.20^{hi}	555.30±3.12^{a}	41.17±4.51^{h}
70	3	Untreated	51.81±0.35^{cd}	8.51±0.08^{e}	35.26±0.45^{d}	36.27±0.42^{d}	131.94±0.77^{i}	26.34±0.34^{f}	131.94±0.77^{i}	300.83±5.03^{bc}
		Blanched	48.95±0.13^{b}	7.57±0.15^{d}	42.07±0.29^{k}	42.74±0.28^{i}	95.68±2.78^{k}	28.81±0.16^{cde}	95.68±2.78^{k}	303.17±8.96^{b}
		Ascorbic acid	65.02±0.72^{jk}	11.36±1.38^{i}	38.66±0.58^{gh}	40.31±0.92^{gh}	114.71±2.92^{j}	20.00±1.31^{k}	114.71±2.92^{j}	47.50±2.00^{h}
	5	Untreated	60.24±1.02^{h}	6.43±0.10^{c}	36.93±1.02^{ef}	37.49±1.00^{de}	398.41±3.12^{d}	18.55±0.67^{l}	398.41±3.12^{d}	240.83±8.62^{f}
		Blanched	56.13±0.03^{fg}	3.50±0.06^{a}	50.20±0.33^{no}	50.32±0.33^{m}	393.00±0.89^{d}	24.34±0.20^{g}	393.00±0.89^{d}	264.50±1.00^{d}
		Ascorbic acid	65.81±0.57^{k}	4.24±0.40^{ab}	36.21±1.78^{de}	36.46±1.75^{d}	261.83±7.00^{e}	13.33±0.52^{m}	261.83±7.00^{e}	37.50±2.65^{h}
	Temperature (T)		***	***	***	***	***	***	***	***
	Slice thickness (ST)		NS	***	***	***	***	**	***	***
	Pretreatment (P)		***	***	***	***	***	***	***	***
	T x ST		***	***	***	***	***	***	***	***
	T x P		***	***	***	***	***	***	***	***
	ST x P		***	***	***	***	***	***	***	***
	T x ST x P		***	***	***	***	***	***	***	***

Values with different superscripts in the same column are significantly different at P <0.05

Treatment effect significant at *P <0.05; **P < 0.01; ***P <0.001; NS not significant at P > 0.05

treatments except in terms of slice thickness where no such impact was noticed. In general, the L* values increased as both slice thickness and drying air temperature increased but assumed a decreasing order of ascorbic acid > control > blanching in terms of pretreatment options. These observations could primarily be linked to the time taken to dry i.e the shorter the drying time the lower the change in the samples' brightness [44]. This explains why the 3 mm thick slices dried at the more elevated temperatures which had shorter drying times were observed to have relatively higher brightness. However, no clear trends were observed for the three-factor interactions other than that of pretreatment (ascorbic acid > control > blanching) under each slice thickness and drying temperature. Inhibition of enzymatic browning and shorter drying time could account for the increased in L* values in the samples pretreated with ascorbic acid solution. The relatively lower L* value recorded by blanched samples could partly be due to non-enzymatic browning as a result of the blanching temperature. Nevertheless, all the values of L* obtained indicate a high degree of brightness since they are above the dark region (L* = 0) even though the dried samples were less bright than the fresh.

The attribute a* was significantly ($p < 0.001$) affected by all the treatment conditions, which caused the disappearance of the green color and the revelation of redness (+ve a* values). The values increased proportionally with slice thickness but decreased with an increase in temperature and with pretreatment in the order ascorbic acid > blanching > control. The trend observed for the drying air temperature could also be associated with shorter drying time and inhibition of enzymatic browning as explained earlier. The observations relative to slice thickness and pretreatment could partly be ascribed to extended drying and blanching. No linear trends were observed for the interactions. Similar effects and trends were observed for b* values, with slight variations such as blanching > ascorbic acid > control and a slight decline at 70 °C. These trends, on one hand, showed that the 3 mm slice thickness, untreated and higher temperature might produce a* and b* values closer to the fresh fruit. On the other hand, higher a* and b* values indicate the revelation of more red- and yellow-pigmented compounds such as lycopene, carotenoids and anthocyanins which are very vital for human health.

Color saturation (C*) explicitly followed the course of b*. This shows that b* values contributed more to the outcome of C* than a* values due to their larger magnitudes, hence the observed trend. Hue values were also generally affected ($p < 0.001$) by all the treatments. The values decreased as slice thickness increased but increased as drying temperature increased. Values of a* seemed to have influenced these hue trends as the two are inversely related. The overall color change (ΔE*) significantly decreased as the drying air temperature increased. This could be linked to the time taken to dry, the resultant effect of the amounts of heat generated by the respective temperatures. The ΔE* values relatively increased with an increase in the slice thickness, attributable to more heat impact as a result of prolonged drying. An exception existed at the 70 °C where the 5 mm slices were less impacted as against the 3 mm slices, possibly due to variation in exposed surface area to the elevated heating condition. Pretreatment also significantly impacted the ΔE* values i.e the ascorbic acid samples generally had the least change, followed by the untreated and the blanched samples had the highest. This indicates that blanching before drying causes more overall color change as compared to the other two options.

3.5. *β-carotene and vitamin C contents of dried G. erubescens fruit samples*

All the factors had significant ($p < 0.001$) main and interactive effects on the β-carotene and vitamin C contents determined (Table 3). Also, the dried *G. erubescens* fruits were more concentrated in vitamin C content than in the fresh state due to loss of moisture, except for β-carotene content where the dried samples had lower values than the fresh. However, Stacewicz-Sapuntzakis et al. [52] ascribed the reduction in β-carotene content of the dried product to immense degradation during drying.

Averagely, pretreatment negatively affected the β-carotene content of the samples as the grand means for the blanched and ascorbic acid samples were significantly lower than that of the untreated samples. β-carotene is heat-sensitive and thus undergoes degradation when heated, especially at elevated temperatures [52] which could be the reason for the general low values recorded by steam-blanched samples. Though highly lipophilic, β-carotene can undergo minimal dissolution in water [53,54]. β-carotene is also reported to be unstable under acidic conditions [53]. Its instability in acidic media and marginal solubility in water possibly accounted for the lower values with regard to the ascorbic acid pretreatment. This, therefore, suggests that pretreatment may not be necessary for β-carotene retention in *G. erubescens* fruit and thus, saves resources required for the pretreatment process. The 5 mm slice thickness averagely yielded better β-carotene values compared to the 3 mm slice thickness, relatable to minimal direct heat exposure as the thickness increased. Heat catalyzes the degradation of bioactive compounds including carotenoids. A wavy trend was recorded in terms of temperature with 60 °C recording the highest value and 50 °C the lowest. The impact of heat intensity and drying time could partly account for this observation. Interactively, the 5 mm ascorbic acid-treated samples dried at 60 °C had the highest (555.30 ± 3.12 μg/100 g) β-carotene content while the 3 mm ascorbic acid-treated samples dried at 50 °C had the lowest (42.70 ± 3.21 μg/100 g).

Vitamin C, an immune booster and scurvy fixer, is highly water-soluble and heat-sensitive. Its values decreased as slice thickness and drying air temperature increased due to higher volatility at prolonged drying time and enhanced temperature intensity. Santos & Silva [15] and Vega-Galvez et al. [55] attributed the decline of vitamin C values at higher temperatures to enhanced oxidation reaction, partly explaining the values of this study. The values recorded by the ascorbic acid-treated samples were significantly lower than the blanched and untreated samples. This shows that the dipping in the ascorbic acid solution resulted in leaching of the vitamin C because of its high solubility. The loss of the vitamin was further compounded during the drying process because of its heat sensitivity. The positive performance of the blanching, in this case, could be linked with the formation of a filmy protective layer on the periphery of the blanched slices by melting sugars against adverse thermal effects [56]. Overall, the 3 mm untreated samples dried at 40 °C recorded the highest (319.50 ± 6.08 mg/100 g) vitamin C while the lowest (37.50 ± 2.65 mg/100 g) was recorded by the 5 mm ascorbic acid-treated samples dried at 70 °C.

4. Conclusion

The study was designed to investigate the effect of slice thickness, pretreatment and drying air temperature on the drying behavior, color, β-carotene and vitamin C content of *G. erubescens* fruits. The findings showed an increased drying rate with a decrease in slice thickness and an increase in drying air temperature but no clear trend with pretreatment. The results further showed the Page model to have the best fitting for the experimental moisture ratio data of the *G. erubescens* fruits following its lower RMSE values (0.0001–0.0063) and higher R^2 values (0.9998–0.9999). The D_{eff} values (5.31×10^{-11} to 4.14×10^{-10} m^2s^{-1}) increased as the slice thickness and drying air temperature increased but had no linear trends with pretreatment. The E_a ranged from 14.35 to 44.78 $kJmol^{-1}$, with the highest being recorded by 5 mm control samples and the lowest by the 3 mm blanched samples. The treatments also affected ($p < 0.05$) the color properties, generally reducing the brightness (L*) and causing the revelation of more redness (a*) and yellowness (b*) as well as increasing the color saturation (C*) of the samples. The total color change (ΔE*) of the samples generally decreased as the drying air temperature increased but increased as the slice thickness increased. The ascorbic acid samples had the least color change, followed by the untreated samples while the blanched samples had the highest change. Overall, the 5 mm ascorbic acid treated samples dried at 70 °C had the least color change (13.33 ± 0.52). The blanching and dipping in ascorbic acid solution generally yielded lower β-carotene and vitamin C values as compared to the untreated samples. The 3 mm ascorbic acid pretreated samples dried at 50 °C recorded the lowest β-carotene (42.70 ± 3.21 μg/100 g) while the 5 mm ascorbic acid pretreated samples had the lowest vitamin C (37.50 ± 2.65 mg/100 g) at 70 °C. The study showed that the pretreatments and drying air temperatures used had mixed effects on the drying characteristics, color, β-carotene and vitamin C of *G. erubescens* fruit slices. The findings, therefore, indicate that a compromise may have to be made on the aforementioned processing conditions in order to meet the desired attributes of one's interest. However, subsequent studies could be done to incorporate dried *G. erubescens* fruit products for the development of new functional foods.

Data availability statement

The data that support the findings of this study are available from the corresponding authors upon reasonable request.

CRediT authorship contribution statement

Joseph Kudadam Korese: Conceptualization, Formal analysis, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Matthew Atongbiik Achaglinkame:** Formal analysis, Investigation, Writing – original draft.

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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