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Effect of different pretreatments and drying methods on the drying kinetics and quality of turmeric (*Curcuma longa*) rhizomes

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ABSTRACT

Turmeric (Curcuma longa L.) is one of the spices commonly used globally due to its health-promoting properties. The rhizomes are however perishable due to their high water content. In this study, the effect of different pretreatments and drying methods, viz. hot air drying (HAD) at 60 ℃ and forced air solar drying (FASD), on the drying kinetics, water activity, color, ß-carotene, and vitamin C contents of turmeric rhizomes were investigated. Prior to the experiments, fresh turmeric rhizomes were sliced into 3 mm thickness and treated either by steam blanching or immersion in an ascorbic acid solution. The untreated samples served as a control. The results showed that blanching and ascorbic acid treatments decreased the drying time by 11% and 31% each under the HAD and 30% and 18% under FASD when compared with the control, respectively. The water activity of steam blanching, ascorbic acid, and control samples dried under HAD and FASD was below 0.60, which is sufficient to inhibit spoilage. Ascorbic acid pretreated samples dried under HAD, and FASD resulted in significantly ($P<0.05$) lower total color change (HAD=14.06; FASD=12.79) with greater retention for vitamin C (HAD: 895.67±1.76 mg/100g; FASD=858.73 mg/100g) contents. Beta-carotene content was, however, not altered ($p> 0.05$) by the pretreatment, drying method, and their interaction. In conclusion, pretreating turmeric rhizomes with the ascorbic acid solution before HAD at 60°C will be ideal for preserving the color properties, vitamin C and ß-carotene contents.

***Keywords**: Turmeric rhizomes, pretreatment, drying method, drying kinetics, quality attributes.*

INTRODUCTION

Turmeric (*Curcuma longa*) is a member of the Zingiberaceae family, and it is generally grown to a great extent in tropical and subtropical regions all through the world (Chattopadhyan et al., 2004). It is commonly used as a spice and coloring agent and is well-known for its nutritional and therapeutic properties (Komonsing et al., 2022a). Turmeric is also known for its medicinally important properties, such as anti-inflammatory, anti-diabetic, wound healing, and anti-fertility activities (Roshan and Gaur, 2017). Thus, it is effectively used to treat diabetes, sprains, malignant diseases, Alzheimer's, chronic diseases, etc. (Roshan and Gaur, 2017). Turmeric rhizome is highly nutritious and a good source of curcumin content, which can add value to many products (Komonsing et al., 2022a; Mane et al., 2018). However, freshly harvested turmeric rhizomes are highly perishable due to their high moisture

content (70-80%) (Singh et al., 2010). The rhizomes are also seasonal, which limits their consumption and food application. Thus, reducing the moisture content of the fresh rhizome through the application of preservative methods is imperative for extended shelf-life and extended use.

Drying is one of the oldest methods that can be used to make the rhizomes easy to handle and inhibit microbial growth (Pittia and Antonello, 2016). Numerous drying technologies have been developed and used for various agricultural products (Ling et al., 2015). Open sun drying has been used in some parts of the world to dry turmeric (Komonsing et al., 2022b). Though open-sun drying is inexpensive and requires no special knowledge of application, the quality of the dried products is significantly compromised as the products being dried are directly exposed to dust, fumes, sunlight, microbial and pest attack, and other quality-jeopardizing environmental factors (Chumroenphat et al., 2021; Maskan et al., 2002). Solar drying is one of the inexpensive alternative applications resulting from solar energy systems and has the potential for use in drying various agricultural and marine products (Mustayen et al., 2014; Fudholi et al., 2010). Convective hot air drying is also frequently used for drying fruits, vegetables, and marine products due to its low costs. Nonetheless, the method requires rather extended drying times and elevated temperatures to complete the drying process, resulting in nutrient losses and colour alteration (Kumar et al., 2021; Tello-Ireland et al., 2011). Therefore, the selection and use of an optimal drying method play a crucial role in retaining quality parameters during the preparation of dried turmeric samples.

Previous researchers have reported that the drying rate and quality of high-value agricultural materials can be enhanced by pretreatments such as blanching and immersion in chemicals before drying (Deng et al., 2019). Xiao et al. (2017) reported that enzyme deactivation and destruction of microorganisms are concurrently accomplished during the thermal blanching of fruits and vegetables. Gan et al. (2017) in their study also reported the effects of drying and blanching in hot water on the retention of bioactive compounds in turmeric. Korese and Achaglinkame (2022) revealed that drying *Gardenia erubescens* at 60 °C without pretreatments preserves most quality parameters. However, there is currently a paucity of information regarding hot air drying (HAD) and forced air solar drying (FASD) of turmeric rhizomes and the use of pretreatment to minimize quality losses. Thus, this study explored the effect of two pretreatment options (steam blanching and soaking in ascorbic acid solution) and drying methods such as HAD and FASD on the drying kinetics, color, water activity, vitamin C and beta carotene contents of turmeric slices.

MATERIALS AND METHODS

Sample preparation

Fresh turmeric rhizome samples (Figure 1) were obtained from a supplier in the Tamale market in the Northern Region of Ghana. The turmeric rhizomes were washed thoroughly under tap water and then cut to a thickness of 3 mm using a Ritter E16 slicer (Ritter GmbH, Germany). The turmeric samples were then subjected to two pretreatment options: steam blanching at 100℃ for 3 min and immersing in 2% w/v ascorbic acid for 3 min (Korese and Achaglinkame, 2022). A sample weight of 300g was pretreated at a time for each option and allowed to drain for 1 min before drying. A third category of sliced rhizomes, which did not undergo any treatment, was used as the control.

Drying equipment

Hot air drier

The treated and control sliced turmeric samples were subjected to HAD using a tabletop cabinet dryer (Hohenheim HT mini, Innotech-ingenieursgesellschaft mbH, Altdorf, Germany) (Korese et al., 2021). The drying air

temperature was set at 60 °C (Sharma et al., 2021; Singh et al., 2010).

Figure 1: Fresh turmeric rhizomes

Solar drier

Forced convective solar dryer, "HT mini solar" (Innotech-ingenieursgesellschaft mbH, Altdorf, Germany) (Figure 2) which is installed at the Engineering and Mechanization Workshop of the University for Development Studies, Nyankpala Campus (09°25'N and 00°58'W), Ghana was used for the experiments. The solar drying system consisted of a solar air collector, a drying cabinet, a 0.25 m diameter 24 V DC fan to provide the required airflow rate through the product to be dried, and a photovoltaic module of 50 W capacity. The solar air collector was covered with a UV-stabilized PE film. This configuration served as a duct for hot air and took the appearance of a rectangle with a cross-sectional area of approximately 4 m^2 and a height of 0.25 m. The substructure of the solar air collector and the drying cabinet was constructed with 40 mm PU insulation panels and 15 mm Duropal-HPL material, respectively. There were arrangements for fixing ten 0.56 x 0.45 m stainless steel trays. Drying experiments for both treated and control sliced turmeric samples started at 8: 00 am and stopped at 17: 00 pm. In this study, the drying chamber temperature and humidity were 40.07 °C – 43.34 °C and 36.80% – 41.97%, respectively. The temperature and relative humidity of the drying chamber was measured using Testo 174H sensors with an accuracy of ±0.2 °C and ±3% RH.

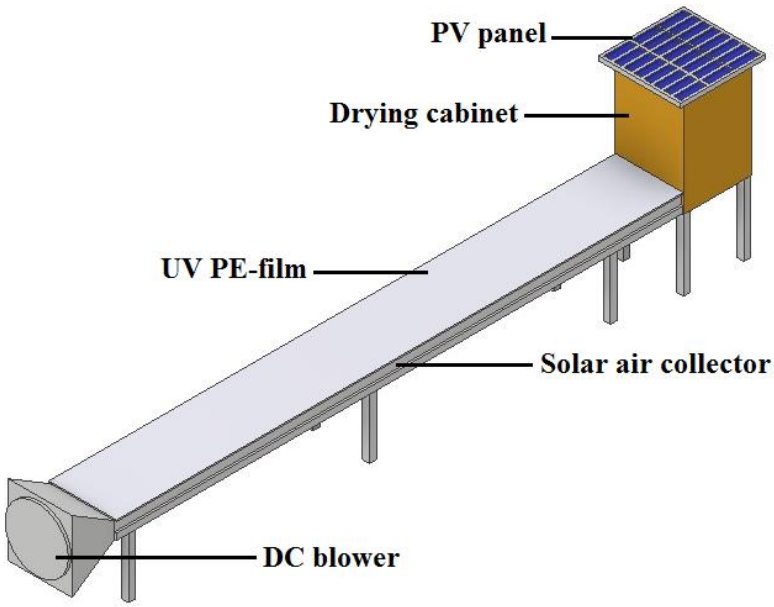

Figure 2: 3D view of HT mini forced convective solar cabinet dryer

Common experimental procedure

For all drying experiments, moisture loss from the turmeric samples during drying was recorded at 15 min intervals with the aid of Kern PCB 1000-1 electronic balance (Kern and Sohn GmbH, Germany) till the samples attained a constant weight. This operation was carried out within 25 s (Wongwises and Thongprasert, 2000) and did not interfere with the drying air conditions. In addition, all dried turmeric samples were stored in airtight low-density polyethylene bags for further quality analysis.

Drying kinetics of turmeric rhizomes

The drying curves were obtained from the plots of the dimensionless moisture ratio (MR, Equation 1) as a function of the drying time for each of the pretreatments (Olawale and Omole, 2012).

$$MR = \frac{M_t - M_e}{M_0 - M_e} \quad (1)$$

Where, M_t is the moisture content (g water/g dry matter) at any given time t (min), M_0 is initial moisture content (g water/ g dry matter), M_e is equilibrium moisture content (g water/ g dry matter).

Drying kinetics reveal good information about the drying process of turmeric rhizomes. Therefore, to identify the drying period during HAD and FASD, plot of drying rate versus moisture content was established using Equation 2 (Roknul Azam et al., 2019).

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (2)$$

Where DR is the drying rate (g water/g dry matter/min), M_t and M_{t+dt} are moisture contents at time t (min) and t+dt, respectively.

Despite the importance of drying kinetics, modeling of thin-layer drying was still necessary as it provide a good understanding of controlling critical parameters of a drying process as well for simulation and optimization of the different types of drying systems (Onwude et al., 2016; Jain and Pathare, 2004). Therefore, the Page model (Equation 3) was used to describe the drying behavior of turmeric rhizomes. The selection of this model was based on preliminary experiments which showed the best fit to the experimental drying data of turmeric rhizomes. The Page model has been successfully used to describe the drying behavior of different types agricultural products (Srikanth et al., 2018; Zhu and Shen, 2014; Singh and Pandey, 2012).

$$MR = \exp(-kt^n) \quad (3)$$

Where k, n are model constants and t is time (min).

Water activity measurement

Water activity (a_w) of the dried turmeric products was measured using Labswift-a_w (Novasina AG, Switzerland) following the procedure outlined by Korese et al. (2021).

Color determination

The color properties such as lightness (L*), redness (a*), yellowness (b*), and total color change (ΔE) of fresh and dried turmeric rhizomes were measured using a handheld colorimeter (CR-400, Minolta Co. Ltd., Japan) following the procedure described by Korese et al. (2021).

Beta-carotene and vitamin C contents determination

Beta-carotene content was determined according to the procedure outlined by Mbondo et al. (2018) and Rodriguez-Amaya and Kimura (2004) with slight modifications. In brief, 5 g each of fresh and dried turmeric rhizome samples was mixed with 1.5 g of celite. About 10 mL of cold acetone was then added to the mixture, finely grinded in a mortar and pestle and transferred into 50 mL volumetric flask using a sintered glass funnel. The residual was filtered and washed with fresh cold acetone until devoid of color. Petroleum ether (PE) (50 mL) was dispensed into a separatory funnel and the acetone extract slowly added followed by distilled water to eliminate residual acetone.The two phases were allowed to separate, and the lower aqueous phase was removed and discarded.The PE phase containing carotenoids was collected into a volumetric flask and the

solution made to pass through a funnel containing anhydrous sodium sulfate (15 g) to dry the layer and topped up to 50 mL with PE.Beta-carotene was determined at 450 nm using UV/VIS spectrophotometer (Excellence UV5, Mettler Toledo, Switzerland). The absorbance of standard solutions was used to generate the standard curves.

Vitamin C content was determined using the 2,6-dichlorophenolindophenol titrimetric method (AOAC, 2010; Ndawula et al., 2004). Briefly, 5 g each of fresh and dried turmeric sample was extracted in 5% metaphosphoric acid and filtered through a Whatman filter paper. The extracted solution (10 mL) was titrated against 0.21% of 2,6-dichlorophenolindophenol dye to obtain the ascorbic acid. An equivalent amount of the extraction solution taken as a blank was titrated against standard 2,6-dichlorophenolindophenol and a correction for it made in the final titre. The test was performed in triplicate and the ascorbic acid content was expressed as mg per 100 g sample on a matter basis.

Statistical analysis

The data were presented as mean±standard deviation, using two-way ANOVA in SPSS (IBM SPSS Version 23) at a 5% significance level.

The model coefficients were determined using nonlinear regression analysis in Microsoft Excel (2016) with solver function, whereas the quality of fit of the model was assessed using a coefficient of determination (R^2, Equation 4), root mean square error (RMSE, Equation 5) and the sum of square error (SSE, Equation 6) (Franco et al., 2017; Salim et al., 2016).

$$R^2 = \left(\frac{\sum_{i=1}^{n}\left(X_{exp}-X_{pred}\right)^2}{\sum_{i=1}^{n}\left(X_{exp}-\bar{X}_{exp}\right)^2}\right) \quad (4)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(X_{pred}-X_{exp}\right)^2} \quad (5)$$

$$SSE = \sum_{i=1}^{n}\left(\mathrm{MR}_{\mathrm{exp,i}}-\mathrm{MR}_{\mathrm{pre,i}}\right)^2 \quad (6)$$

Where X_{exp} and X_{pred} represent the experimental and predicted MR values, respectively, n is the number of observations and z is the number of constants in the model equation.

RESULTS AND DISCUSSION

Drying kinetics

Figure 3 and 4 shows relationship between MR versus drying time and drying rate versus moisture content for turmeric rhizomes dried using HAD at 60 °C and FASD. The average initial moisture content of the fresh turmeric sample was 77.16% which fell within the 70 – 80% range reported by Singh et al. (2010). The moisture content decreased continuously with drying time (Figure 3). Drying of turmeric rhizomes in any of the experimental treatments exist solely in the falling rate period, which showed that the internal moisture diffusion phenomenon is dominant i.e. it controlled the drying process. The drying rates results are similar with some related literature on drying of orange-fleshed sweet potato and cocoyam (Sturm et a., 2022), turmeric slices (Komonsing et al., 2022b) and palmyra seed-sprout fleshy scale slices (Korese et al., 2021). The results from Figure 3 show that the drying methods influenced the time taken for the samples to dry, which is consistent with the literature (Flores et al., 2007). Considering HAD, among the pretreatments, the ascorbic acid had the shortest drying time (240 min), followed by blanching (285 min) and control (315 min). This means that ascorbic acid and blanching pretreatments decreased the drying time of the turmeric rhizomes by approximately 31% and 11%, respectively. However, the drying times of 300 min, 330 min, and 390 min were recorded for blanching, ascorbic acid, and control, respectively, under the FASD method. This shows that the blanching and ascorbic acid pretreatments decreased the drying time by 30% and 18%, respectively, when compared with the control samples. Several authors have suggested considerable decreases in the drying times when blanching with steam or ascorbic acid pretreatments were used for drying various

agricultural products. These included Rybak et al. (2021) for red bell pepper, Milani et al. (2020) for banana, Abano et al. (2013) for mango, Tunde-Akintunde and Ogunlakin (2011) for pumpkin and Doymaz (2008) for leek slices. Generally, the increase in the drying rate of the blanched turmeric rhizome samples is related to the altered cell structure such as disruption of the cell membrane and expelling of air entrapped inside the tissues, especially intercellular gas, thus aiding moisture movement from its internal regions (Deng et al., 2019; Xiao et al., 2017). Also, the ascorbic acid pretreated samples had an enhanced drying rate due to leaching of the samples by the ascorbic acid, thereby creating fine pores that facilitate the rapid removal of moisture from the samples during drying (Elangovan and Natarajan, 2021). The drying time for the various pretreatments was longer in FASD methods than in HAD due to fluctuating temperatures during the drying period.

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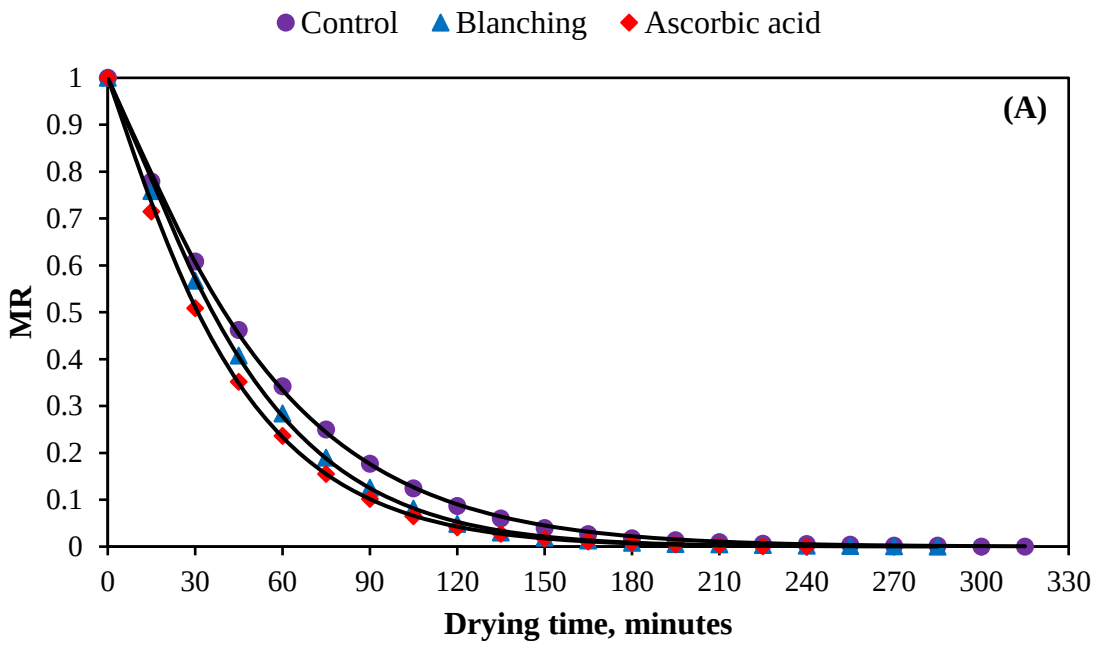
The solid lines in Figure 3 represent Page model (Equation 3) fitting, which shows a good agreement between experimental and predicted moisture ratios. The regression parameters of the Page model and statistical test applied are presented in Table 1 for the different drying methods and pretreatments. The values of the R^2 ranged from 0.9976 to 0.9999, while the RMSE and SSE values ranged from 1.328×10^{-3} to 7.612×10^{-3} and 3.53×10^{-5} to 6.31×10^{-3}, respectively. The modeling outcome in this study demonstrates the suitability of the Page model in describing the drying kinetics of turmeric rhizomes. Figure 5 compares the experimental MR data with the Page model's predictions. The data points generally band around 45° straight line on the plots, thus supporting the suitability of this model to describe the drying behavior of both treated and control turmeric rhizomes



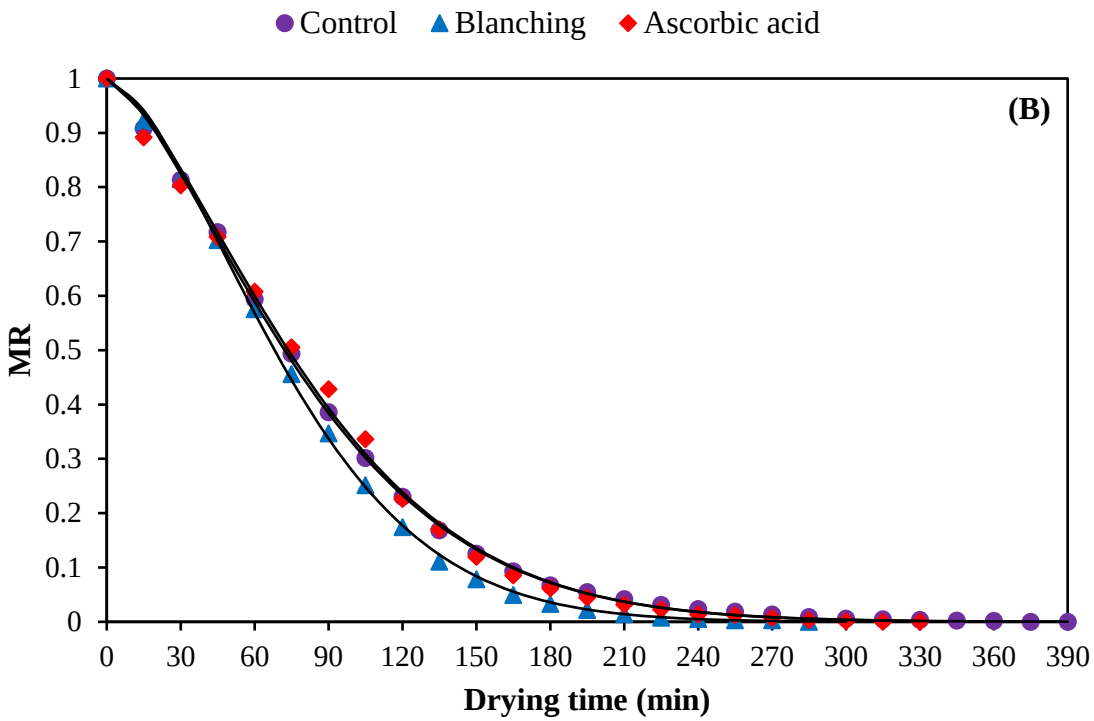
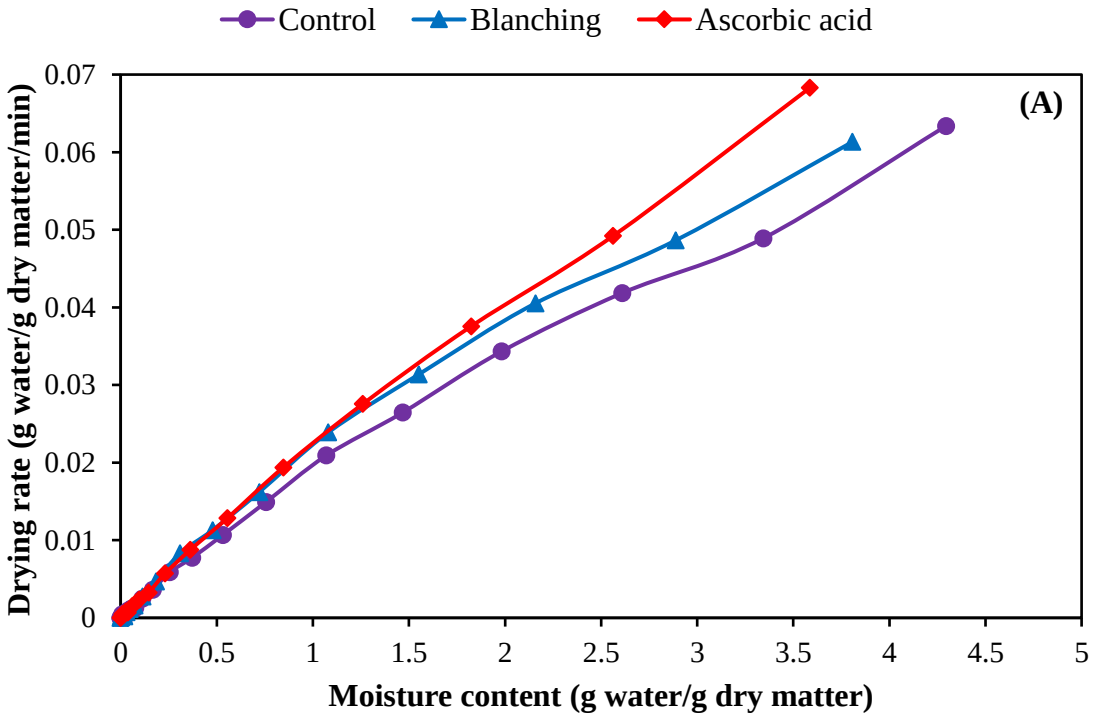


Figure 3: Moisture ratio versus drying time at different pretreatments of turmeric rhizomes. (A) Hot air drying and (B) solar drying. Solid lines correspond to the Page model



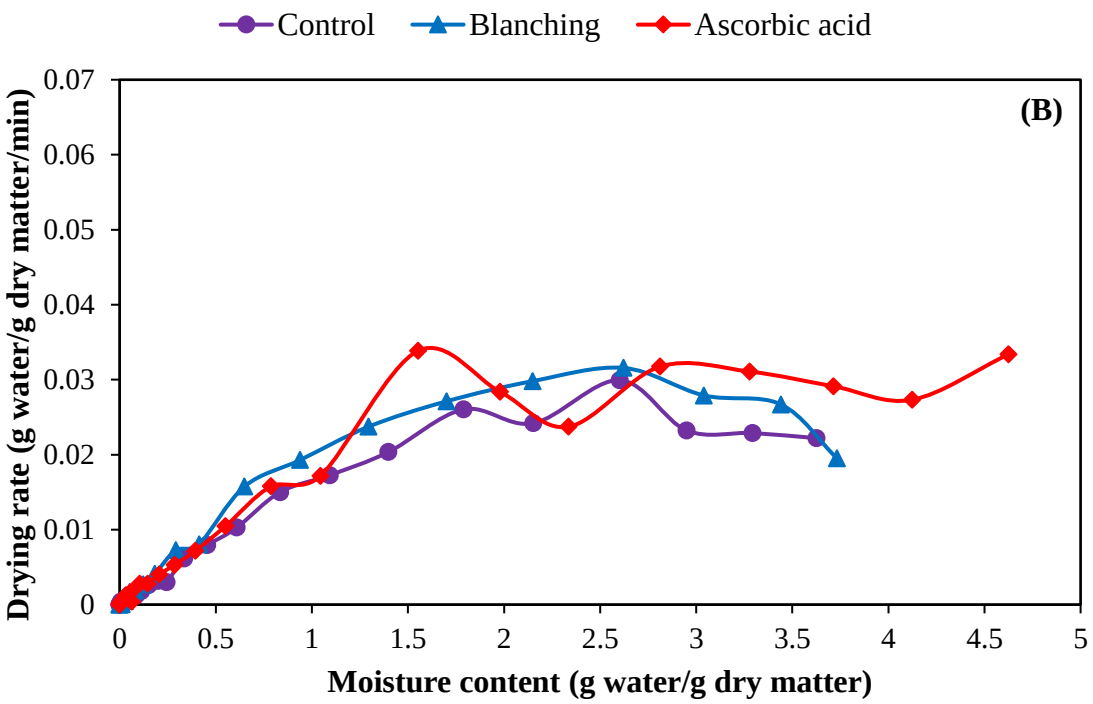


Figure 4: Drying rate versus moisture content at different pretreatments of turmeric rhizomes. (A) Hot air drying and (B) solar drying

Table 1: Constants of the Page model describing the drying kinetics of turmeric rhizomes using different drying methods

Drying method	Pretreatment	Model constants		Statistical analyses		
		k	n	R^2	RMSE	SSE
Hot air drying	Control	0.010568	1.133611	0.9997	0.005269	6.11×10^{-4}
	Blanching	0.009419	1.199469	0.9997	0.002521	1.27×10^{-4}
	Ascorbic acid	0.014955	1.117807	0.9999	0.001328	3.53×10^{-5}
Solar drying	Control	0.001341	1.460037	0.9995	0.007218	1.41×10^{-3}
	Blanching	0.000763	1.613806	0.9995	0.007612	1.22×10^{-3}
	Ascorbic acid	0.001157	1.487394	0.9976	0.016560	6.31×10^{-3}

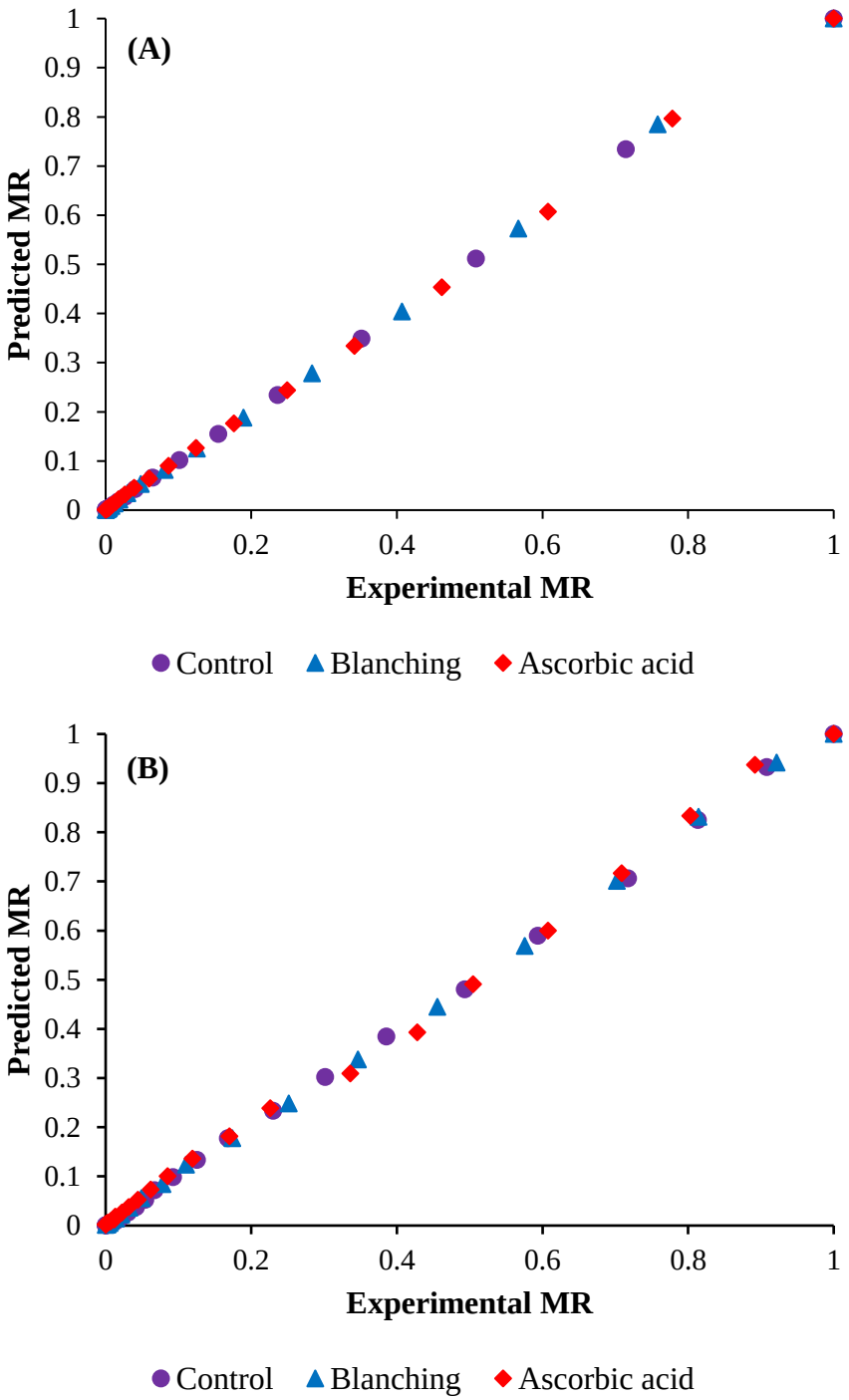


Figure 5: Experimental and predicted moisture ratios for different pretreatment of turmeric rhizomes. (A) Hot air drying and (B) Solar drying

Final moisture content and water activity

Water activity indicates the amount of free water available for microbial and biochemical activities. The higher the a_w value, the higher the chances of occurrence of microbial and biochemical activities and the faster the rate of deterioration of the food material and vice versa. Thus, a_w greatly dictates the shelf life of food substances, including dried fruits and vegetables. Nevertheless, a_w values below 0.60 render microbial and biochemical activities

almost non-existent (Tang and Yang, 2003; Perera, 2005). All the a_w values recorded for the samples in this study were far below 0.60, irrespective of the pretreatment and the drying method used (Table 2). Nevertheless, turmeric rhizome samples dried under HAD had lower a_w values than corresponding FASD-dried samples. This is because HAD at 60 °C was the most effective means of moisture removal compared to FASD (see Figure 3). It can also be seen from Table 2 that, the control samples dried under HAD had significantly ($p< 0.05$) lower a_w values than the blanched and ascorbic acid-treated samples. According to Vandeweyer et al. (2017), increasing the drying times leads to lower water activities. However, a_w value for the control samples dried under FASD was significantly ($p< 0.05$) higher compared to the blanched and ascorbic acid-treated samples. The control dried samples under FASD might have adsorbed more moisture due to differences in pore size and binding site (Ojike et al., 2022). The final moisture content of all the samples was below 10%, which is considered ideal for the prolonged storage of dried food materials such as fruits (Deng et al., 2019). This shows that all the dried turmeric rhizome slices of the various treatments can be stored for a reasonably long period before losing their microbial safety.

Table 2: Average final moisture content and water activity of turmeric rhizome with different drying methods and pretreatments

Drying method	Pretreatment	Final moisture content	Water activity
Hot air drying	Control	4.23 ± 0.09^{a}	0.256 ± 0.00^{a}
	Blanching	4.45 ± 0.16^{a}	0.280 ± 0.00^{b}
	Ascorbic acid	5.78 ± 0.22^{b}	0.278 ± 0.00^{b}
Solar drying	Control	9.65 ± 0.23^{e}	0.388 ± 0.00^{e}
	Blanching	7.49 ± 0.03^{c}	0.375 ± 0.00^{d}
	Ascorbic acid	8.93 ± 0.07^{d}	0.352 ± 0.00^{c}
P-value		0.000	<0.001

Values are means ± standard deviations (n=3). Values in the same column with different superscript letters are significantly different ($p <0.05$).

Color

Colour characteristics are the most common parameters measured in dried food products as they influence consumers' choices, preferences, and the market value of dried products (Chua et al., 2001).Table 3 shows colour properties of dried turmeric rhizomes. The average values for the color parameters of fresh turmeric rhizomes were: L = 47.57, a*= 18.39 and b*=56.97. Drying method and pretreatment had a significant ($p<0.05$) effect on color properties of dried turmeric products, except L* for the control samples (Table 3). Under the HAD method, the ascorbic acid treated samples had the highest L*, a*, and b* (45.92±2.38, 18.82±1.82, 50.86±3.91), followed by the control (42.63±1.05, 10.60±1.68, 41.75±3.81) and the blanched samples the lowest (34.85±1.25, 9.66±1.87, 36.64±2.70), respectively (Table 3). For ΔE, ascorbic acid treated samples showed the lowest (14.06±1.08) value, followed by the control (18.00±1.97), while the blanched samples had the highest ΔE value (25.57±1.73). A similar trend is also seen for the color parameters among the pretreatments under the FASD. The color of the ascorbic acid-treated samples under both drying methods is almost the same as that of the fresh. The findings show that immersing the turmeric rhizome slices in ascorbic acid before drying preserved the color of the slices when compared with the blanched or untreated samples. Though

ascorbic acid and blanching treatments inhibit enzymatic browning, these findings indicate pigment degradation in the case of the blanching because of the high temperature involved, which resulted in a considerable change in color in the samples. Similar observations about pigment degradation of blanched purple-fleshed sweet potato was reported by Marzuki et al. (2021) during hot air drying.

Table 3: Colour properties of dried turmeric rhizome as influenced by pretreatments and drying methods

Drying method	Pretreatment	L*	a*	b*	ΔE
Hot air drying	Control	42.63 ± 1.05^{b}	10.60 ± 1.68^{b}	41.75 ± 3.81^{b}	18.00 ± 1.97^{c}
	Blanching	34.85 ± 1.25^{a}	9.66 ± 1.87^{a}	36.64 ± 2.70^{a}	25.57 ± 1.73^{d}
	Ascorbic acid	45.92 ± 2.38^{c}	18.82 ± 1.82^{e}	50.86 ± 3.91^{d}	14.06 ± 1.08^{ab}
Solar drying	Control	43.27 ± 2.62^{b}	12.73 ± 1.13^{cd}	46.56 ± 1.89^{c}	15.18 ± 1.84^{b}
	Blanching	41.54 ± 1.22^{b}	12.10 ± 1.88^{c}	42.47 ± 1.17^{b}	17.68 ± 1.09^{c}
	Ascorbic acid	50.27 ± 2.62^{d}	13.19 ± 1.33^{d}	47.92 ± 3.60^{c}	12.79 ± 1.80^{a}
Effects					
Pretreatment (P)		**	**	**	**
Drying method (DM)		*	*	**	**
P*DM		**	*	*	**

Values are mean ± standard deviation, * and ** denote $p < 0.05$ and $p < 0.001$, respectively at 95% confidence level.

Beta carotene content

Beta-carotene is a precursor for vitamin A, vital for normal vision, the immune system, and reproduction. The results showed that the β-carotene content of the turmeric slices was not altered ($p > 0.05$) by the pretreatment, drying method, and their interaction. Even though the values were in a close range, the hot-air dried ascorbic acid-treated samples recorded the highest value (12.58 µg/100g) while the solar-dried blanched samples had the lowest (11.79 µg/100g) (Figure 5). Under both drying methods, the blanched samples had the lowest β-carotene values, which can be attributed to thermal degradation due to blanching and subsequent drying. Comparatively, the dried samples had more β-carotene content than the fresh ones. This is because the removal of moisture results in an increased concentration of nutrients in the dried product. However, the values of the pro-vitamin A (β-carotene) recorded in this study are lower than the 344 mg/100g reported by Imoru et al. (2018) for vitamin A in turmeric rhizomes.

Vitamin C content

Vitamin C is an important vitamin for the body as it improves immunity. It is heat-labile and also water-soluble. The vitamin C content was greatly affected by the pretreatments and drying methods (Figure 6). The ascorbic acid-treated samples recorded the highest values under both drying methods, with the overall highest value recorded by the hot-air dried ascorbic acid-treated samples (895.67 mg/100g). The blanched samples dried under the FASD method had the least (205.53 mg/100g) vitamin C content. The relatively lower values recorded by the blanched samples can be attributed to losses through volatilization due to the heat of the blanching steam. On the other hand, the values recorded by the ascorbic acid-treated samples can partly be linked with the possible absorption of the acid, which is vitamin C in nature, and the volatilization of the ascorbic acid deposited on the surface of the samples as a result of the immersion in the ascorbic acid solution in place of the vitamin C in the samples. Vitamin C can be taken as an index of nutrient quality of foods because of its high heat

sensitivity. Hence, its retention indicates the retention of other vital nutrients such as vitamins A and B complex (Marfil et al., 2008). Thus, it can be inferred that the ascorbic acid-treated samples may have higher values of other vitamins in the turmeric rhizome slices. However, the vitamin C values recorded in this study are higher than the (84 mg/100g) reported by Imoru et al. (2018).

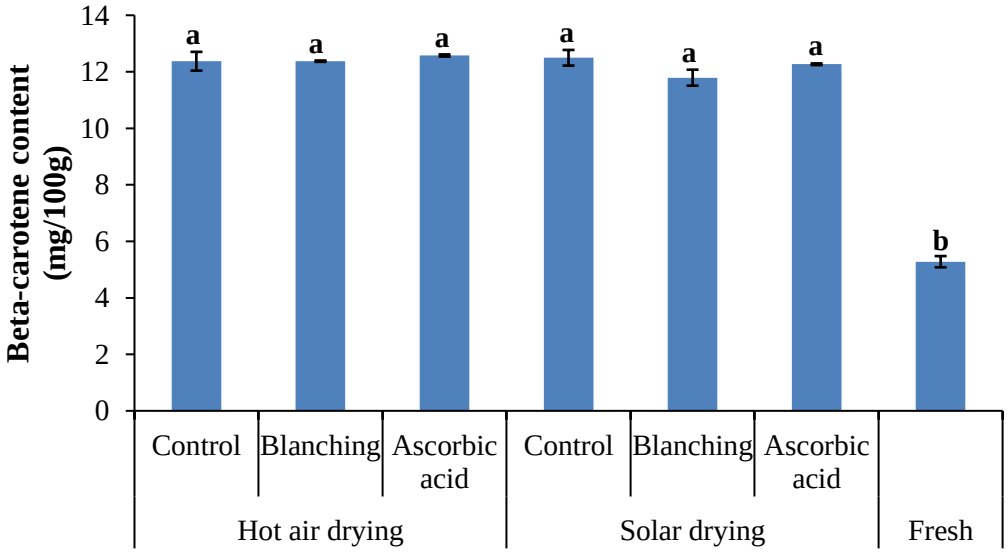


Figure 5: Beta-carotene content of dried turmeric rhizomes as affected by different pretreatments and drying methods. Vertical bars above the column represent the standard errors of three replicates.

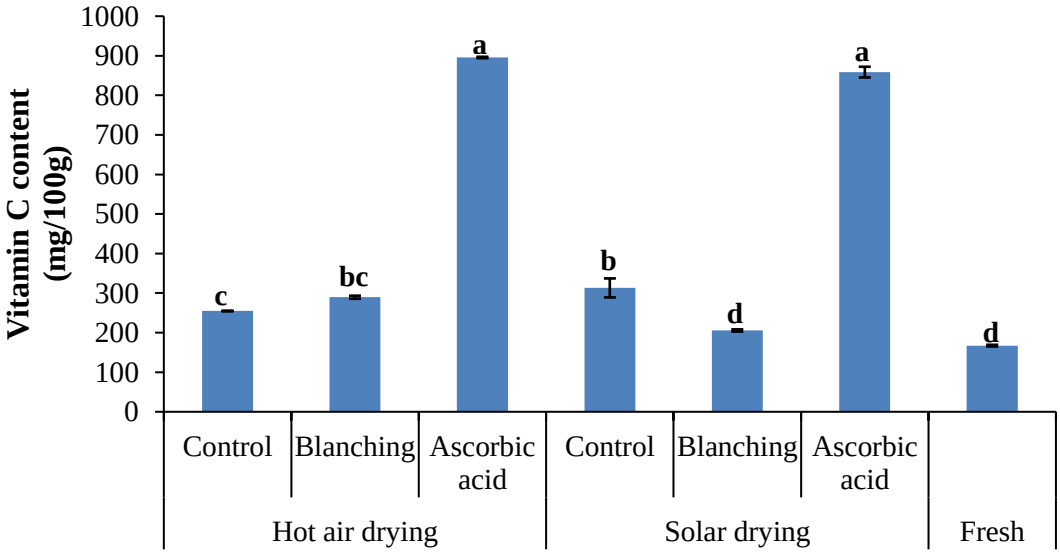


Figure 6: Vitamin C content of dried turmeric rhizomes as affected by different pretreatments and drying methods. Vertical bars above the columns represent the standard errors of three replicates.

CONCLUSIONS

This study examined the effect of different pretreatments, HAD, and FASD on turmeric rhizomes' drying behavior and quality characteristics. The results showed that the blanching and ascorbic acid treatments

decreased the drying time by 11% and 31% each under the HAD method and 30% and 18% under FASD when compared with the control, respectively. The dried samples' water activity values were below 0.60, indicating a potentially longer shelf life. The ascorbic acid-treated samples had higher color retention followed by the control, while steam blanching adversely affected the color of the samples. Also, the ascorbic acid treatment yielded the best vitamin C and beta-carotene contents, followed by the control and blanching the lowest. HAD and FASD had no significant ($p > 0.05$) effect on β-carotene. In conclusion, pretreating turmeric rhizomes with ascorbic acid solution (2% w/v) and HAD at 60°C was more effective in preserving the color properties, vitamin C and β-carotene contents of the crop as compared to FASD. Nonetheless, there is a need for further research on the effect of various concentrations of ascorbic acid treatments on the drying behavior of turmeric rhizomes.

Competing interest

The authors declare that they have no conflict of interest

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