Effect of citric acid pretreatment on drying kinetics of tamarillo in a greenhouse solar dryer

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Abstract

The production and consumption of tamarillo (*Solanum betaceum*) is gaining momentum due to its immense nutritional, health, and commercial potential. However, like many other horticultural products, high postharvest losses are incurred in tamarillo production. In particular, decay is a major problem. Drying is a viable option that can address this problem and significantly increase the shelf life of tamarillo. Consequently, the objective of this study was to evaluate the effect of citric acid pretreatment on the drying kinetics and quality of tamarillo slices. The tamarillos were dried in a passively operated even-span greenhouse solar dryer (8 m long, 4 m wide, and 3.6 m high to the ridge) covered with a 200 µm thick ultraviolet-stabilised polyethylene film. Solar radiation, temperature, relative humidity, moisture content, colour, firmness, and vitamin C content were periodically measured, and the data were analysed statistically. The citric acid-pretreated and control (untreated) tamarillo slices were dried from an initial moisture content of 655% (db) to a final moisture content of 16.25% and 22.50% (db), respectively, in 10 hours. In addition, the pretreated slices attained a higher average drying rate of 42.01±0.23 g/g/hr compared to 40.23±0.12 g/g/hr attained by the control slices. Further, the Page model best described the drying kinetics of both tamarillo samples with R^2, χ2, and RMSE values of 0.9975, 0.0004, and 0.0005, respectively. The pre-treated samples had better colour retention with a total colour change of 15.07±1.12 compared to 35.99±0.98 attained in the control samples. Moreover, the pretreated tamarillo slices attained a lower percentage firmness increment of 281.82±3.21% compared to 337.5%±1.54 attained in the untreated samples. Further, the pretreated tamarillo slices had 42.94±0.41% vitamin C retention compared to 40.17±0.67% retention in the control samples. Generally, pre-treating tamarillo slices with citric acid improves their drying kinetics and both physical and nutritional qualities.

Keywords: Greenhouse solar dryer, tamarillo, colour retention, firmness, vitamin C.

1.0 Introduction

The rising incidence of lifestyle diseases has seen an increase in both awareness and consumption of healthy foods. Consequently, this has necessitated the production of high-quality fruits and fruit-based products due to their richness in bioactive compounds such as antioxidants, vitamins, dietary fibre, and minerals (Méndez et al., 2016). Among these fruits is

tamarillo (Solanum betaceum), which is commonly known as tree tomato due to its high physical resemblance to tomato. The fruit contains a significant proportion of vitamins A, B, C, and E, starch, protein, anthocyanins, carotenoids, and soluble fibre (Mutalib et al., 2017). Moreover, tamarillo has antioxidative, allergenic, antinociceptive, anti-inflammatory, anti-obese, and antiproliferative properties (Diep et al., 2022). It is consumed directly or in processed form, such as juice, desert, or powder form.

Tamarillo is a high-moisture fruit, which makes it a significantly perishable fruit with a short shelf life of approximately 8 weeks under ambient storage conditions (Munir et al., 2018). Consequently, the fruit is prone to post-harvest losses, in particular, bottom rot and quality deterioration. Although storing tamarillo at a low temperature of 3.5–4.5°C increases its shelf life to 12–14 weeks, it results in the development of chilling injuries, which may encourage fungal invasion (Al Mubarak et al., 2019). This necessitates, therefore, the need to invent and use alternative techniques that will mitigate postharvest losses in its production and hence economically empower the farmers.

Drying lowers the moisture content and consequently reduces microbial activity, thereby slowing down deterioration. Besides increasing the shelf life of the tamarillo, drying reduces transportation and packaging costs as well as gives the food industry the opportunity to process it into secondary products such as tamarillo powder. Various studies on the drying of tamarillos have been reported (Ramakrishnan et al., 2018; Liu et al., 2022; Al Mubarak, 2018), in which spray drying was used to produce tamarillo powder. Other drying methods, such as sun drying, freeze drying, and cabinet drying, have also been used in processing tamarillos (Stephen et al., 2022). However, there is no study in the literature on the drying of tamarillos in a greenhouse solar dryer. While greenhouses are becoming increasingly important for vegetable production (Mutwiwa et al., 2007; Max et al., 2012), the transfer of this principle to postharvest, specifically drying, is gaining momentum. As a technology, Ndirangu et al. (2018) established that greenhouse solar drying has significant economic benefits such as reduced cost of drying, high output, and a high-quality product with a high hygiene rating compared to other drying methods such as open-sun drying. Furthermore, Mweu et al. (2021) demonstrated that covering solar dryers with films that filter out UV radiation improves the drying kinetics and quality of tomatoes. Hence, it is a suitable technology that can greatly contribute to the reduction of postharvest losses in tamarillos.

Besides the numerous benefits of drying, it also results in the degradation of vital nutritional components of dried products as a result of heat-induced reactions. The degree of degradation varies with the drying technology and drying conditions used, as well as the pretreatment of the product before it is subjected to drying. The pretreatments include the use of chemical solutions such as alkali and acid, thermal blanching, gas (sulphur dioxide and carbon dioxide) treatment, and non-thermal processes such as freezing and ultrasound treatment (Sablani, 2006). Various studies, such as Deng et al. (2019), have established that the use of both chemical and physical pretreatments has an effect on drying kinetics, quality, and deterioration during the drying and subsequent storage of dried fruits and vegetables. As such, the objective of this study was to evaluate the effects of citric acid pretreatment on the drying kinetics and quality

of tamarillo in a greenhouse solar dryer.

2.0 Materials and methods
2.1 Experimental setup
The study was undertaken at Jomo Kenyatta University of Agriculture and Technology (JKUAT), Kenya. The institution is located in Kiambu County, Juja (37.05°E longitude, 1.19°S latitude, 1532 m altitude). The experiment was carried out under passive conditions in an 8-metre-long, 4-meter-wide, and 3.6-meter-high greenhouse solar dryer. The dryer was cladded with a 200-µm-thick ultraviolet (UV)-stabilized polyethylene film (Figure 1). The dryer was installed on a black-painted concrete floor to enhance heat absorption and hygiene within the dryer.

Figure 1: A photograph of the greenhouse solar dryer used in the study.

2.2 Experimental procedure
Experiments were carried out from November 8th to November 13th, 2021, from 08:00–17:00 hours. Fresh tamarillos were purchased from Mwifa Farm in Eldoret, Kenya, and transported in a cold box on the same day to the Agricultural Processing Laboratory at JKUAT. The fruits were then sorted out to remove the bruised and spoiled ones and washed with clean running water, after which they were dried using a piece of cloth. The tamarillos were then peeled and cut into 5 mm-thick slices using a clean, sharp knife. For each batch, 1.5 kg of the sliced tamarillos was divided into three equal portions of 500 g and labelled. The first 500 g portion was subjected to oven drying at 103 ± 2 °C for 24 hours to determine the moisture content. One of the remaining two portions was then pretreated with citric acid by dipping it in freshly squeezed, undiluted lemon juice for 15 minutes, and the free surface water was drained using a clean piece of cloth before being subjected to drying. The third portion was dried with no pretreatment to act as a control. For purposes of drying data collection, 200 g of the tamarillo slices were monitored throughout the experiment. This process was replicated three times, and the results were averaged.

2.3 Data collection and analysis

Key drying condition parameters, namely, solar radiation, temperature, relative humidity, and tamarillo's weight, were monitored concurrently as the drying progressed. A hand-held digital solar power metre (Model TM206, Taiwan) was used to measure solar radiation every 30 minutes. Ambient and greenhouse temperatures and relative humidity were measured using LogTag recorders (Model HAXO-8, Australia), while a digital weighing scale (CAS SW-II-30, India) was used to measure the weight of the fruits during drying. Temperature and relative humidity data from the LogTag loggers were downloaded using LogTag Analyzer 3 software (Version 3.1.11, 2020, Australia) for analysis. Microsoft Excel 2016 (Microsoft, US) was used to carry out statistical analysis of the acquired data, out of which corresponding relations were established.

The tamarillos' moisture content was established using the oven drying method, with the final dry base moisture content of the tamarillos determined using Equation 1, in which M_{db}, Wi, and W_d represent the moisture content (dry basis) and initial and dry weights, respectively.

$$M_{db} = \frac{W_i - W_d}{W_i} \times 100\% \qquad (1)$$

The drying rate of the tamarillos was determined using Equation 2, in which R_c represents the drying rate (g/g/h), dM and dt represent change in mass (g) and time (h), respectively, t is the total drying time (h), W_i is the initial weight of the sample (g), and W_d is the final weight of the dried sample (g).

$$R_c = \left(\frac{dM}{dt}\right) = \frac{W_i - W_d}{t} \qquad (2)$$

The modelling of the tamarillo's drying kinetics was done by fitting the moisture ratio data to four thin layer drying models (Table 1) using regression analysis carried out using the Microsoft Excel 2016 solver function (Microsoft, US).

Table 1: Thin layer drying empirical models

Model Name	Model*
1. Page	$MR = \exp(-kt^n)$
2. Modified Page	$MR = \exp(-kt)^n$
3. Henderson and Pabis	$MR = a\,\exp(-kt)$
4. Midilli	$MR = \exp(-kt^n) + bt$

*a, b, c, k, k_1, k_2, n are parameters of the models.

The performance of the models in predicting the drying kinetics was evaluated using coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE) as indicated in Equations 3-5, in which $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ is the ith predicted moisture ratio, N is the number of observations, and z is the number of constants (Taheri-Garavand et al., 2011). According to Kucuk et al. (2014), the best quality of fit is provided by the model with the closest R^2 value to 1 ($R^2 \cong 1$) and the lowest χ^2 and RMSE values.

$$R^2 = 1 - \left[\frac{\Sigma_{i=1}^{N}\left(MR_{pre,i}-MR_{exp,i}\right)^2}{\Sigma_{i=1}^{N}\left(\overline{MR}_{pre,i}-MR_{exp,i}\right)^2}\right] \tag{3}$$

$$\chi^2 = \frac{\Sigma_{i=1}^{N}\left(MR_{exp,i}-MR_{pre,i}\right)^2}{N-z} \tag{4}$$

$$RMSE = \sqrt{\frac{1}{N}\Sigma_{i=1}^{N}\left(MR_{exp,i} - MR_{pre,i}\right)^2} \tag{5}$$

2.4 Colour

The colour of the tamarillo samples was measured using a hand-held colour metre (Model TES 135A, China). The metre was first standardised using the white standard tile provided by the manufacturer before taking the measurements. Lightness (L*), redness (a*), and yellowness (b*) parameters of the tamarillos were recorded and used to calculate chroma (C), which indicates colour intensity, and hue angle (H^o), which indicates pureness of different colours (Seerangurayar et al., 2019) using Equations 6 and 7. For each sample, the measurements were repeated three times.

$$C = \sqrt{a^{*2} + b^{*2}} \tag{6}$$

$$H^o = \tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{7}$$

The degree of colour retention of the dried samples from fresh tamarillos was evaluated using the total colour difference (ΔE). The value of ΔE was calculated using Equation 8, in which L_o^*, a_o^*, and b_o^* are colour parameters of the fresh produce while L*, a*, and b* are corresponding parameters of the dried product.

$$\Delta E = \sqrt{(L_0^* - L^*)^2 + (a_0^* - a^*)^2 + (b_0^* - b^*)^2} \tag{8}$$

2.5 Firmness determination

A penetrometer (Compac-100, Sun Scientific Co. Ltd., Japan) was used to measure the firmness of the fresh and dried tamarillo slices. Samples were obtained and subjected to the test every 2 hours during drying. The penetrometer's probe was set to penetrate the samples to a depth of 2 mm, and the corresponding force (N) needed to pierce to this depth was recorded. Three sample slices from each batch were measured separately, and an average of the three forces was obtained. The average force required to penetrate the pre-treated and control slices was then compared. The increment in firmness was as well calculated as illustrated in Equation 9, in which ΔF, F_f, and F_d represent the change in firmness of fresh and dry tamarillo, respectively.

$$\Delta F(\%) = \frac{F_d - F_f}{F_f} \times 100 \tag{9}$$

2.5 Vitamin C

Vitamin C content was evaluated using the proximate composition analysis method to measure ascorbic acid in the dried samples as specified by the Association of Official Analytical Chemists (AOAC, 1990). The tamarillos were sampled from the dryer after every 2 hours and ground. A sample of 10 g was then homogenised with 50 g of the extraction solution (2 g oxalic acid/100 g sodium). A 20-gramme aliquot was taken and diluted to 50 ml with the extraction solution in a volumetric flask, after which it was vacuum filtered. Aliquots of 10 ml of the filtrate were then titrated with 2,6-dichlorophenolindophenol (0.01 g/100 g solution). The analysis end point was detected visually, and all the analyses were replicated three times. The value of vitamin C content in the tamarillos was then determined using Equation 10, in which Vit C is the vitamin C content (mg/100 gDM), VE is the vitamin C equivalent of 1 ml of 2,6-dichlorophenolindophenol (DCPIP) (mg/ml), V_1 is the total extract volume (ml), V_2 is the titrated extract volume (ml), S is the sample weight (g), and Y is the sample dry matter (%).

$$\text{Vit C} = \frac{\text{Titre} \times \text{VE} \times V_1 \times 100 \times 100}{V_2 \times S \times 1000 \times Y} \qquad (10)$$

Vitamin C retention in the dried tamarillos was then determined by comparing the dried vitamin C content (V_d) to the fresh vitamin C content (V_f), as illustrated in Equation 11 (Kiburi et al., 2020).

$$\text{Vitamin C retention (\%)} = \frac{V_d}{V_f} \times 100 \qquad (11)$$

3.0 Results and discussion

3.1 Dryer performance

Solar radiation, temperature, and relative humidity were monitored during drying as they influenced the performance of the greenhouse solar dryer and consequently the drying kinetics of the tamarillo slices. Figure 2 depicts the variation of solar radiation, ambient and greenhouse solar dryers' temperatures, and relative humidity with the time of day. During the experiment, maximum and minimum solar radiation of 1032 and 12.7.6 W/m^2 were recorded at 13:30 and 08:00 hours, respectively, with an average hourly radiation of 704.23±16 W/m^2. The ambient temperature ranged from 14.01 to 31.85 ºC, with the maximum temperature being registered at 15:30 hours. Similarly, a range of 31.4–62.06 ºC of greenhouse temperature was recorded, with an average of 51.22±8.9 ºC during the drying. On the other hand, 31.86±2.3% average hourly ambient relative humidity was recorded. This was higher compared to the corresponding average of 12.27% recorded in the greenhouse solar dryer.
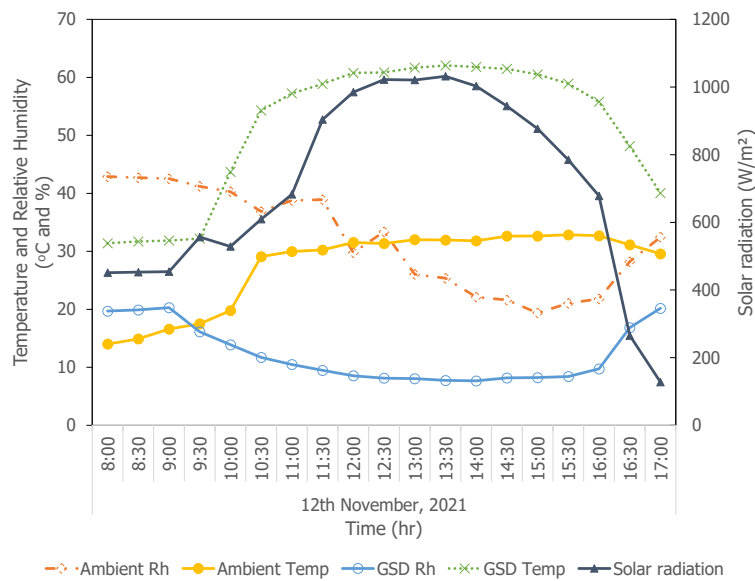
Figure 2: Variation of solar radiation, temperature and relative humidity with time on a typical representative day (12th November 2022).

The temperature difference between the greenhouse solar dryer and the ambient temperature ranged between 10.47 and 30.11 ºC, with an average of 23.73±84 ºC. This temperature difference was found to be statistically significant, with a p-value of 0.011 (p<0.05). Similarly, the corresponding relative humidity difference was established to be statistically significant at a p-value of 0.012 (p<0.05). The difference ranged between 11.14% and 29.44%, with an average hourly difference of 19.58±5.1%. Overall, a directly proportional relationship was established between solar radiation and ambient as well as greenhouse solar dryers' temperatures. Temperature increased during the day as it was driven by solar radiation, while relative humidity had an opposite trend. Mweu et al. (2022) reported similar observations during the thin-layer drying of tomato slices in a greenhouse solar dryer.

The drying conditions resulted in a reduction in the tamarillos moisture content from 665 % (db) to 16.25% and 22.50% (db) final moisture content for pretreated and control tamarillo slices, respectively, in 10 hours. The reduction in moisture content during the drying of tamarillo slices is depicted in Figure 3. The entire drying process occurred during the falling rate period, indicating that the main mechanism governing moisture removal from the product was diffusion. Picado et al. (2021) reported similar observations during the drying of tomato slices in a tunnel dryer.
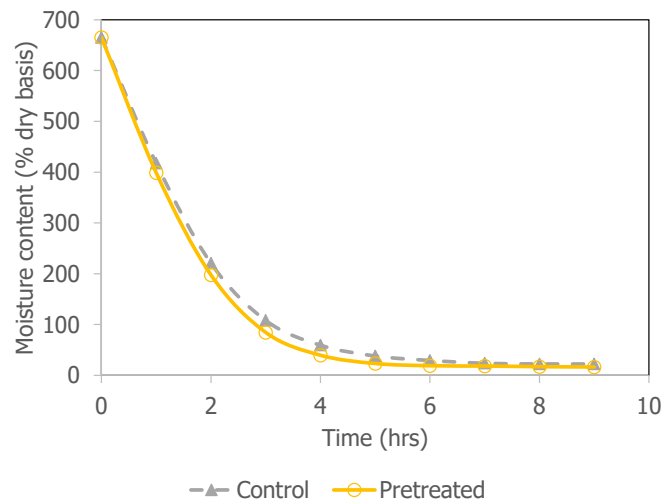
Figure 3: Moisture reduction curve in tamarillo slices during drying.

Figure 4 shows the drying rate of both pretreated and control tamarillo slices. In both curves, the drying rate increased during the initial one hour of drying to a peak of 266.25 and 247.50 g/g/hr before gradually reducing as drying progressed. This reduction is a result of the reduction of free water on the surface of the tamarillos due to the increasing drying temperature in the greenhouse solar dryer. Moreover, the shrinkage of tamarillo samples as drying progressed reduced their porosity, making it difficult to extract moisture from the inner parts of the samples, consequently reducing the drying rate (Witrowa-Rajchert & Rząca, 2009). Overall, it was established that the citric acid-pretreated samples had a faster drying rate compared to the untreated control samples. On average, a drying rate of 42.01±0.23 g/g/hr was attained in the pretreated samples compared to 40.23±0.12 g/g/hr attained in the control samples. Nevertheless, the differences between the drying rates of the two samples were not significantly different, with a p-value of 0.062 ($p > 0.05$). The relatively higher drying rates in the pretreated tamarillos are attributed to citric acid's ability to increase the tamarillo's cell membrane permeability, resulting in increased water diffusivity. Similar observations were reported by Doymaz (2020) during the drying of kiwifruit slices.
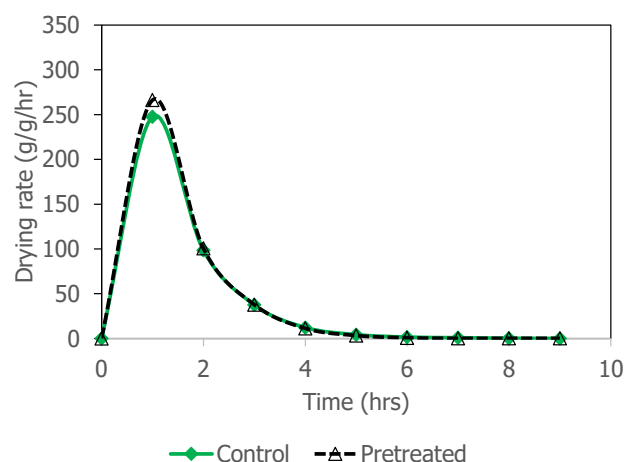

Figure 4: Drying rates of pretreated and control tamarillo slices in greenhouse solar dryer.

The evaluation of the thin layer drying kinetics was carried out using linear regression analysis to fit the drying data into the four drying models illustrated in Table 1. A comparative analysis of the four models established that the Page model attained the best fit for both samples at R^2 values of 0.9975, the lowest χ^2 values of 0.0004, and the lowest RMSE values of 0.0005. Figure 5 shows the graphs of actual and predicted moisture ratios versus drying time. Consequently, it was concluded that the Page model provided the best description of the drying kinetics of both the citric acid-pretreated and untreated tamarillo slices in a greenhouse solar dryer. Similar results were reported by Méndez et al. (2016) during ultrasound-assisted convective drying of tamarillo and mango slices.
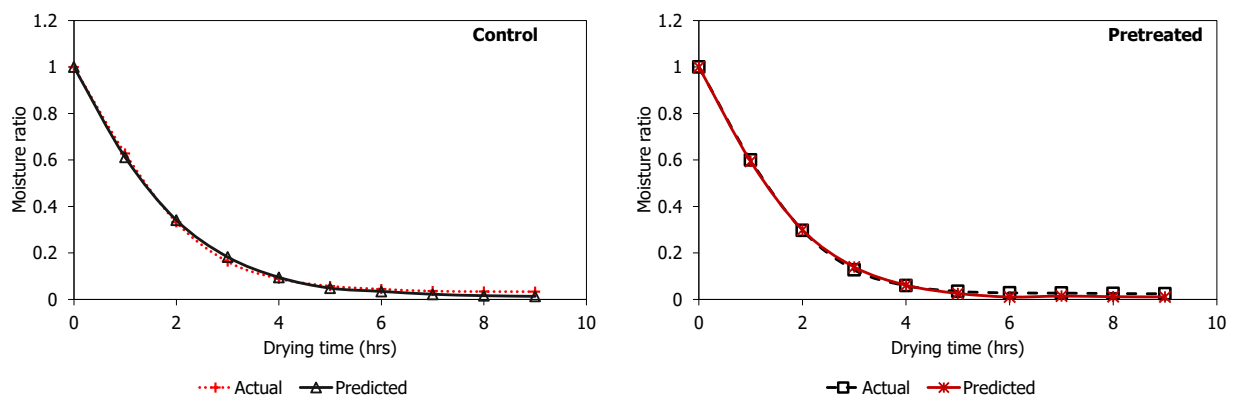

Figure 5: Drying rates of control and pretreated tamarillo slices in greenhouse solar dryer.

3.2 Colour change

The colour parameters of the fresh and greenhouse solar dryer-dried tamarillo slices are presented in Table 2 for both control and citric acid-pretreated samples. The results indicate that the L* and b* values of both the control and pretreated samples decreased after drying. Consequently, the final product was darker than the fresh product. However, the control tamarillo slices were darker compared to the pretreated samples. The darkening is a result of browning reactions in the slices, which is a common phenomenon in dried fruits and vegetables.

Table 2: Hunter colour parameters of the fresh and dried tamarillo slices

Hunter colour parameter	Control samples		Pretreated Samples	
	Fresh	Dried	Fresh	Dried
L*	47.15±0.67	17.59±1.42	43.57±0.62	28.84±1.29
a*	20.15±3.33	11.6±3.56	27.14±3.13	29.43±0.33
b*	17.39±0.67	-1.30±0.07	10.76±0.05	8.52±0.37
C	26.86±0.68	11.78±0.57	29.51±0.32	30.70±1.36
h°	39.95±1.68	352.71±0.87	27.14±0.04	16.08±1.33
ΔE	35.99±0.98		15.07±1.12	

In addition, the a* and b* values of the dried tamarillo slices were higher in the pretreated samples than in the control samples. Consequently, the chroma (C) value in pretreated tamarillo slices increased while it was reduced in the control samples. Chaethong and Pongsawatmanit (2015) reported that a high C-value suggested vivid retention of colour due to its association with higher redness (a*) and yellowness (b*) values. The increment in chroma, therefore, suggested that pretreating the tamarillo slices with citric acid enhanced colour retention. Figure 6 shows a comparison of the colour of the fresh, control, and pretreated tamarillo slices. Moreover, the total colour change ΔE, which measures the colour deviation from the reference material, which is fresh tamarillo, was higher at 35.99±0.98 compared to 15.07±1.12 of the pretreated samples. As such, the small ΔE value indicated that citric acid improved colour retention in the dried, pretreated samples. In addition, the difference in ΔE between the control and pretreated samples was statistically significant at a p-value of 0.024 (p<0.05).

Fresh tamarillo slices   Dried control tamarillo slices   Dried pretreated tamarillo slices

Figure 6: Comparison of colour between the fresh, control and pretreated tamarillo slices.

3.3 Firmness

Figure 7 shows the firmness of both the pretreated and control tamarillo slices as the drying progressed. It was observed that the firmness increased gradually with an increase in drying time due to moisture loss. This is attributable to an increase in dry matter as a result of moisture extraction that resulted in hardening of the outer surface and structure collapse in the samples (Nieto et al., 2013). Moreover, the pretreated tamarillo samples were found to have lower firmness with a percentage firmness increment of 281.82±3.21% compared to 337.5%±1.54 in the untreated samples. The difference in firmness is a result of the plasticizing effect of citric acid absorbed by the tamarillo tissues, which prompted the generation of large pores with less hardness (Krokida et al. 2000). However, this difference was not statistically significant at a p-value of 0.375 (p<0.05).
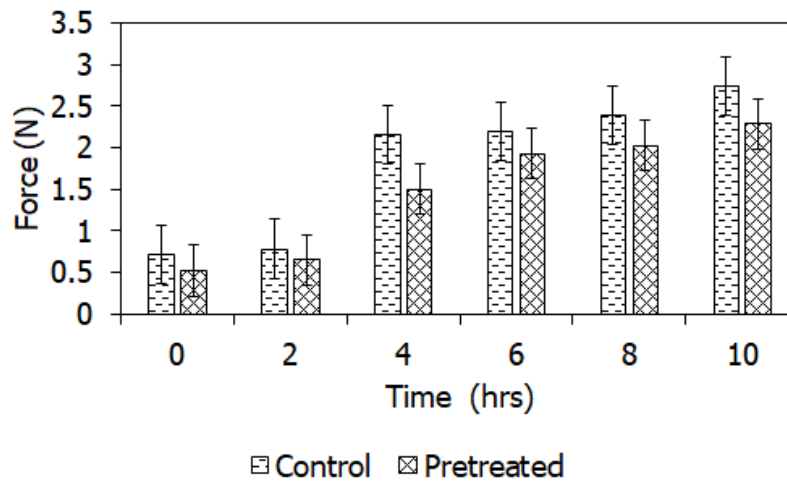
Figure 7: Firmness increment with drying time.

3.4 Vitamin C

Vitamin C is a vital nutritional index in the quality evaluation of dried fruits and vegetables. It is paramount to determine its level in dried products as it is easily degraded due to its high solubility in water, is easily oxidised, and is thermosensitive. In drying, vitamin C degradation varies depending on exposure to the degree of temperature as well as the length of drying time it is exposed to. Consequently, it is often used as a quality indicator in the drying of fruits and vegetables (Santos & Silva, 2008). Figure 8 shows the variation of vitamin C content in tamarillo slices with drying time. For both the control and pre-treated samples, vitamin C content increased in the first 4 hours of drying. The increment is a result of increased concentration, which resulted from rapid loss of moisture and an increase in solute concentration in the samples. However, as drying progressed, vitamin C gradually degraded due to exposure to high temperatures within the greenhouse solar dryer.
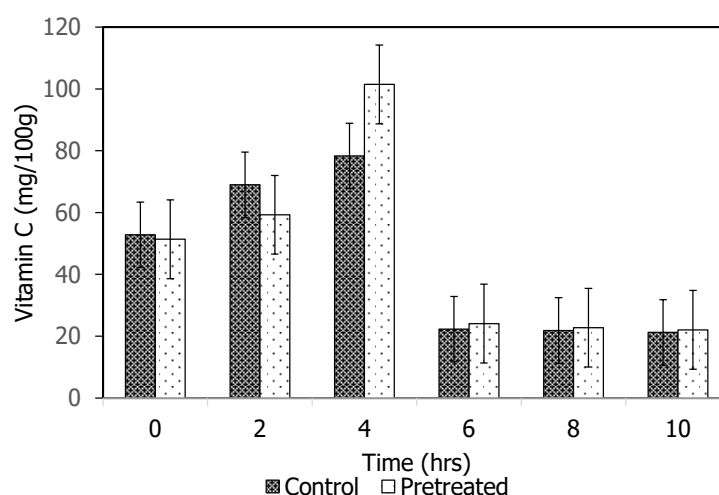

Figure 8. Variation of Vitamin C content in tamarillo slices with drying time.

The initial vitamin C content in the control sample was found to be 52.7972 mg/100 g, which was higher than 51.3572 mg/100g for the pre-treated samples. The slight difference in vitamin C content for pre-treated samples is attributed to leaching during pre-treatment (Sun et al., 2020). After drying, the vitamin C levels in the control and pretreated tamarillo slices were 21.210 mg/100g and 22.054 mg/100g, respectively. This translated to 42.94±0.41% vitamin C retention in the pretreated tamarillo slices, compared to 40.17±0.67% retention in the control samples. Consequently, citric acid pre-treatment caused relatively higher vitamin C retention in the dried tamarillos. Nevertheless, the difference in vitamin C retention between the pre-treated and control tamarillo samples was not significantly different at a p-value of 0.346 ($p > 0.05$). However, the slightly higher vitamin C content in the pre-treated tamarillo slices indicated that the citric pre-treatment was essential in conserving the vitamin C content during the drying process.

4.0 Conclusions

The effects of citric acid pretreatment on the drying kinetics, colour, firmness, and vitamin C of tamarillo slices were investigated in this study. The results obtained indicated that both the dried pretreated and control samples were darker, firmer, and had a lower vitamin C content compared to the fresh samples. The pretreated samples, however, had better drying characteristics, colour and vitamin C retention, and desirable firmness. As such, pre-treating the tamarillo slices with citric acid was established to enhance their drying characteristics as well as their physical and nutritional qualities. Further research should be undertaken to establish the effect of citric acid pretreatment on other quality attributes such as shrinkage as well as the rehydration ratio of the tamarillo slices, as they are crucial determinants of the market acceptability of the dried product.

5.0 Acknowledgement

5.2 Conflict of interest
Authors declare no conflict of interest.

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