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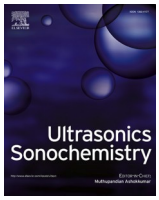

# Effective drying processes for Taikor (*Garcinia pedunculata* Roxb.) fruit by ultrasound-assisted osmotic pretreatment: Analysis of quality and kinetic models

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ABSTRACT

The present study aimed to analyze and establish an effective combination of ultrasound and immersion pretreatment processes for drying *Taikor* (*Garcinia pedunculata* Roxb.) fruits. Taikor slices were first immersed in 10 % sucrose, fructose, and glucose solution. Then, the immersed slices were treated in an ultrasonic bath at 30 °C for 10, 20, and 30 min. Drying operations were carried out at 50, 60, and 70 °C, with a fixed relative humidity of 30 %. The Page, Newton, Henderson and Pabis, and Weibull distribution models were fitted to the obtained drying data to determine the best kinetic model that effectively describes the drying properties of Taikor. After drying operations, changes in quality parameters, e.g., β-carotene, vitamin C, B vitamins, color, antioxidant activities, and microbial loads, were measured to obtain the best drying temperature and the most effective pretreatment combination with minimum loss of nutrients of the sample. Among different kinetic models, both Page and Weibull distribution models showed the best $R^2$ values of 0.9867 and 0.9366, respectively. The chemical properties were preserved to the greatest extent possible by drying at 50 °C with glucose pretreatment. The color parameters were better preserved by fructose pretreatment. Sonication time also had profound effect on the quality parameters of dried *Taikor* slices. However, higher temperature drying required a shorter time for drying and exhibited better performance in microbial load reduction. This study's findings will help to establish an effective drying condition for Garcinia pedunculata fruits.

## 1. Introduction

*Garcinia pedunculata* Roxb. is a citrus fruit locally known as '*Taikor*'. It has a sour taste and is well-known for its medicinal properties. *Taikor* fruit contains vitamin C, vitamin B, and antioxidants [77,39]. Although it was primarily produced in Myanmar and the north-eastern region of India, like many Asian countries, it has become quite popular in Sylhet region of Bangladesh. People of this region know it as 'Tenga', which is popular for its beautiful aroma and used as a flavor in any curry or meal. Also, citrus cuisine uses it frequently due to its powerful therapeutic and nutritional properties [86]. *Taikor* production increases during the peak season, resulting in a flood of products on the market. As a matter of fact, traditional preservation approaches such as the use of chemical agents like synthetic compounds or adding conventional antimicrobials into food like acetic, benzoic, lactic, propionic and sorbic acids, as well as drying methods etc. are continuously being developed to avert *Taikor* loss triggered by microorganisms, enzymatic reactions, and chemical interactions [61].

Among these methods, drying is regarded as the most banal yet crucial preservation method for enhancing the shelf life of any fruits or vegetables. It improves the stability of food by removing moisture and inactivating microorganisms. Moreover, it reduces the number of chemical reactions, such as enzymatic browning, which changes the color and quality of fresh produces [16]. Convective hot air drying is the most common technique as it is the cheapest way of drying food products. A heating source is used to warm the supplied air during this process. This leads to even temperature distribution, cleanliness, and superior quality foods with ideal drying kinetics [63]. Although drying has various advantages, it also has some drawbacks. Several physiochemical, structural, color, and nutritional changes are frequently occurred during the drying process [85,40,13,14]. Depending on the type of food, drying technique, level of treatment, and operational

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parameters, drying can drastically change the chemical structure and nutritional content of food. Food preparation (pre-treatments), drying parameters (especially temperature), and storage conditions can all affect the nutrient content of dried foods [32]. Unfortunately, we cannot overlook this problem; hence, proper design should be implemented before drying.

Different pretreatments have been proven to be very beneficial in overcoming these limitations. Pretreatment before drying can aid in minimizing nutritional loss and, in most cases, keep the structure intact. It prevents the loss of color [20], texture and loss of bioactive components [82]. Now, pre-treatments are typically used to shorten the drying time and accelerate the moisture exchange rate over time [47]. There are numerous pre-treatments, the most well-known of which are osmotic pre-treatment, hot water blanching, ultrasonic treatment, and immersion in various chemical solutions. These are mostly used in various drying situations [3].

Osmotic dehydration or dewatering impregnation soaking (DIS) in concentrated solution has become a common pretreatment in combined techniques over the last few decades [69,93]. The insertion of solutes into the food material distinguishes DIS from other dehydration processes [89]. In previous studies, osmotic pretreatments were found to be effective in maintaining the physiochemical quality of different fruits and vegetables during drying [93,85,14,13]. Hossain et al. [40] studied the effect of osmotic pretreatment on *Garcinia pedunculata* drying. They found that fructose-pretreated samples dried at 55 °C retained the maximum physical and chemical quality after drying. However, this was still insufficient to preserve the quality parameters of fruits. Therefore, we decided to use osmotic pretreatment and ultrasonic water bath treatment. Using ultrasonic waves in liquid medium is known as an ultrasonic bath. High-frequency sound waves cause the formation of cavitation bubbles to agitate the liquid in an ultrasonic bath. Using ultrasound in the food processing industries extends shelf life and supports efficient heat and mass transfer [53]; Hoque et al., 2022). Pretreatment using ultrasonic and osmotic solutions improves the quality and safety of food products while reducing processing time and moisture content (Rodríguez et al., 2018a). From a study by Chandra et al. [18], a DCG-150H model from MRC Lab Equipment with a 6 l capacity was employed for the ultrasonic pretreatment at 30 °C with the osmotic solution, and this pretreatment before drying improved the quality of dried papaya slices.

In the literature, no previous study was found where the combination of ultrasonic and osmotic pretreatment was used to preserve the nutritional qualities of Taikor. Hence, in the present study, the osmotic pretreatment process was done using 10% sucrose, 10% fructose, and 10% glucose at a ratio of fruits: solution = 1:4 (w/w) to prevent the solution from being diluted due to osmosis [14,13]. The samples with the solution were subjected to the ultrasonic water bath. The experiment was conducted at 30±2 °C for 10, 20, and 30 min. Control samples were dipped in only distilled water. Following the pretreatment, convective drying was performed at three temperatures of 50, 60, and 70 °C with a constant 30% relative humidity. The study aimed to investigate the drying effects on Taikor slices with and without osmotic and ultrasonic pretreatment. The drying kinetics were determined by four popular mathematical models. Then, the physiochemical properties of dried - Taikor slices were evaluated to identify the best possible treatment.

## 2. Materials and methods

### 2.1. Sample preparation

Fresh Garcinia pedunculata fruits were obtained from the Bondor Bazar wholesale market in Sylhet, Bangladesh. After careful visual observation, diseased, defective, or damaged samples were disposed of to reduce biological variability. All samples had the same shape, diameter, and weight upon screening. Before use, samples were thoroughly washed with clean water to remove dust, sand, and other unwanted materials. Then, the samples were peeled, and the core was removed, followed by cutting into 1±0.04 cm thick slices using a stainless-steel knife.

### 2.2. Osmotic pre-treatment process in ultrasonic water bath (UWB)

After cutting, samples were immediately immersed in beakers with four different solutions of 10% sucrose (S), 10% fructose (F), 10% glucose (G) and water (W) at 25±2 °C. To prevent a significant reduction in osmotic driving force during processing, the solution to solid mass ratio was 4:1 (w/w), avoiding excessive water removal [14,13]. The beakers containing samples were then placed into an ultrasonic water bath (UWB) (GT Sonic, 6l, 40kHz, 150W, China), where the samples were pre-treated at 30 °C for three different times of 10, 20, and 30 min. The samples were symbolized as S10, S20, S30, F10, F20, F30, G10, G20, G30, W10, W20, and W30 concerning the solution type used and pre-treatment time in the ultrasonic water bath.

### 2.3. Drying process

After pretreatment, the samples were taken out of the water and dried with tissue paper. The samples were then dried in a temperature and humidity-controlled chamber (VS-8111H-150, Vision Scientific Co. Ltd., South Korea), where drying temperatures of 50, 60, and 70 °C and a constant 30% RH were used. The relative humidity (RH) was kept at a minimum level to aid in rapid drying [82,14,13]. On the trays, the samples were arranged in a single layer. Drying data were collected at regular intervals until an equilibrium moisture content was achieved for each drying setting. A constant air velocity of 3 $ms^{-1}$ was maintained for each drying experiment. The moisture content data were recorded at 30 min intervals up to 1h; then, data were taken at 1h intervals until equilibrium moisture content was achieved [43].

#### 2.3.1. Determination of moisture Content

At first, 5 g of the dried samples were kept in an oven dryer (OF-21E, Korea) for 24h at 120 °C. Following that, the dry weight of the samples was determined. The products' moisture content was then calculated on a dry basis by the following Equation (1) [82]:

$$MC_{db} = \frac{W_w - Wd}{W_d} \times 100 \quad (1)$$

where, $MC_{db}$ = moisture content in dry basis,
$W_w$ = weight of the sample before drying,
$W_d$ = dry weight of the sample.

#### 2.3.2. Mathematical models

The drying characteristics of *Taikor* slices were evaluated by different thin layer drying models, namely- Page, Henderson and Pabis, Newton, and Weibull's distribution model as shown in Table 1:

These models are widely utilized for organic materials and most foodstuffs. These models were developed by simplifying Fick's second law. The model developed by Henderson and Pabis is the initial step in the process of finding a generic series solution to Fick's second law. The Newtonian (Lewis) model is a unity-intercept variation of the Henderson and Pabis' model. The drying properties of a variety of agricultural

**Table 1**
Mathematical models (Drying Kinetics Models) used in this study.

| Model name | Mathematical Formula | References |
|---|---|---|
| Page | $MR = \exp(-kt^n)$ | [65] |
| Henderson and Pabis | $MR = a.\exp(-kt)$ | [34] |
| Newton | $MR = \exp(-kt)$ | [17] |
| Weibull's distribution | $MR = \exp[-(t/\alpha)^{\beta}]$ | [92] |

Where, k = drying constant ($h^{-1}$), t = drying time (h), and a and n = drying coefficients, α= scale parameter and β = dimensionless shape parameter.

products were successfully characterized using the Page model, which is an experimental modification of Newton's model [82]. When the scale parameter α is replaced by 1/k, the Weibull model resembles the modified Page model [11]. According to Weibull's distribution model, probability functions are used to characterize the behavior of complex systems with great flexibility [9]. Among all the mathematical models, one of the simplest equations, the Weibull model, only has shape and time parameters. It was used to describe the drying behavior of particular foods [45]. The moisture ratio (MR) was calculated by Eq. (2):

$$MR = \frac{M_t - Me}{M_0 - M_e} \tag{2}$$

where,

MR = moisture ratio (dimensionless).
$M_t$ = moisture content at any given time (g water/ g dry matter).
$M_0$ = initial moisture content (g water/g dry matter).
$M_e$ = equilibrium moisture content (g water/g dry matter).

### 2.3.3. Fitting of mathematical models

The determination coefficient ($R^2$), root mean square error (RMSE), reduced mean square of the deviation or reduced chi-square ($\chi 2$), and sum of squared error (SSE) were considered to determine the model that can sufficiently explain the fluctuation in *Taikor*'s moisture ratio data while drying. To determine the quality of the fit, the determination coefficient was employed as the key parameter. The total dispersion between response values and the model fit is reflected by the SSE. To estimate the quality of fit of a data distribution, identify whether a set of data series are independent, and construct confidence intervals around variance, the reduced mean square of the deviation is utilized. The model with the minimum SSE, RMSE and $\chi 2$ and maximum $R^2$ value was determined to be the best-fitted model. The $R^2$, RMSE, SSE, and $\chi^2$ values were calculated by using Eqs (3)–(6):

$$R^2 = 1 - \frac{\sum_{i-1}^{n}(MR_{(exp,i)} - MR_{(pred,i)})^2}{\sum_{i-1}^{n}(MR_{(exp,i)} - \overline{MR})^2} \tag{3}$$

$$RMSE = \sqrt{\frac{\sum_{i-1}^{n}(MR_{(exp,i)} - MR_{(pred,i)})^2}{N}} \tag{4}$$

$$SSE = \frac{1}{N}\sum_{i-1}^{n}\left(MR_{(exp,i)} - MR_{(pred,i)}\right)^2 \tag{5}$$

$$\Delta 2 = \frac{\sum_{i-1}^{N}\left(MR_{(exp,i)} - MR_{(pred,i)}\right)^2}{N - z} \tag{6}$$

where

$MR_{(exp,i)}$ = dimensionless experimental moisture ratio.
$MR_{(pred,i)}$ = dimensionless predicted moisture ratio.
$\overline{MR}$= mean of all experimental moisture ratios.
N = number of observations.
z = number of constants.

## 2.4. Physiochemical and nutritional quality analysis

### 2.4.1. Surface color measurement

A colorimeter (PCE-CSM4, PCE instruments, Germany) was used to measure the surface colors of dried *'Taikar'* samples. Before the measurements, the apparatus was standardized using a white ceramic plate. Color values (L*, a*, and b*) were determined to compare the color changes between fresh and dried samples. Total color difference (ΔE) was determined following Equation (7), previously used by Lemus-Mondaca et al. [55].

$$\Delta E = \left[\left(L_f^* - L_d^*\right)^2 + \left(a_f^* - a_d^*\right)^2 + \left(b_f^* - b_d^*\right)^2\right] \tag{7}$$

where,

L* = Lightness/darkness,
a* = Redness/greenness, and.
b* = Yellowness/blueness of fresh(f) and dried(d) slices.

Hue and chroma of the sample were determined using Eqs. (8) and (9):

$$\text{HueAngle} = tan^{-1}\left(\frac{b^*}{a^*}\right) \tag{8}$$

$$\text{Chroma} = \sqrt{\{(a^*)^2 + (b^*)^2\}} \tag{9}$$

## 2.5. Determination of bioactive compounds

### 2.5.1. Determination of B vitamins

Different B vitamins were measured spectrophotometrically in fresh and pre-treated dried samples based on the methods compiled by Fernandes et al. [26]. At first, a 0.5 g sample was mixed with 10 mL distilled water and homogenized for 2 min. The mixture was then mixed with 0.25 M (1 mL) sulfuric acid and placed in a water bath for 30 min at 70 °C. Following that, the pH of the extraction liquid was adjusted to 4.5 by using 0.5 M NaOH solution. After that, the solution was placed in an ice bath. The extraction material was then centrifuged for 25 min at 4000 rpm using a benchtop centrifuge (416G, Gyrozen-Benchtop centrifuge, Korea) followed by filtration. After B vitamins were extracted from the supernatant, the absorbance measurements were taken at 254 nm ($B_1$), 320 nm ($B_2$), 265 nm ($B_3$), and 201 nm ($B_6$) in a UV–Vis spectrophotometer (T60U, PG instruments limited, UK). Pure thiamine hydrochloride ($B_1$), riboflavin ($B_2$), nicotinamide ($B_3$), and pyridoxine ($B_6$) were used to create calibration curves.

### 2.5.2. Determination of ascorbic acid (Vitamin C)

The vitamin C concentration was measured spectrophotometrically in the fresh and pre-treated dried samples based on the process used by Keran et al. [49] after a slight modification. A 1.0 g sample was mixed with 10 mL of 0.056 M sodium oxalate and homogenized for 2 min. The extraction liquid was let to rest for 5 min. Then, the homogenate was filtered, and 0.5 mL aliquot was taken in a separate test tube and diluted to 5.0 mL with 0.056 M sodium oxalate. The absorbance measurements were taken at 266 nm by a UV–Vis spectrophotometer (T60U, PG instruments ltd, UK) using 0.056 M sodium oxalate as a blank. The calibration curve of $y = 0.0052x + 0.0161$ was prepared for calculation, where L-ascorbic acid was used as standard.

### 2.5.3. Determination of β-Carotene

The concentration of β-Carotene in Taikor samples was measured by soaking 1 g of dried material and homogenized in 10 mL of distilled water for 2 min. Then, 0.5 mL hexane was added, and the mixture was vigorously agitated for 1 min before being put aside for 5 min to improve mass transfer and then vigorously mixed again for 1 min. Total carotenoids were measured spectrophotometrically at 452nm in the supernatant [79]. The analysis took place in triplicate, and the findings were reported as mg/100 g dry weight based on the developed standard carotene calibration curve, $y = 0.5448x + 0.0118$.

## 2.6. Determination of antioxidant properties

### 2.6.1. Total phenolic content (TPC)

The Folin-Ciocalteu technique was used to measure the total phenolic content in the extracts as reported by Himel et al. [35], with minor changes. Exactly 2.0 mL of 1 M Folin-Ciocalteu reagent and 1.0 mL aliquot of the methanol extract or blank or serial concentration of standard gallic acid were mixed and the mixture was allowed to rest for 5 min. Then 2.0 mL of 7.5 % (w/v) sodium carbonate was added to the mixture. The mixture was thoroughly mixed, then held at a temperature

of 25±2 °C for 30 min followed by centrifugation for 10 min at 2,000 rpm (416G, Gyrozen-Benchtop centrifuge, Korea). The supernatant absorbance was taken at 765 nm against a reagent blank in a UV–Vis spectrophotometer (T60U, PG instruments ltd., UK). The TPC of the extract was calculated using the gallic acid standard curve, y = 0.0495x − 0.0195 and reported as gallic acid equivalents (mg GAE/100 g).

#### 2.6.2. Total flavonoid content (TFC)

The total flavonoid content was measured using the procedure of Rahman et al. [68] with some modifications. At first, 0.5 mL of extracted methanol solutions were mixed with 2.0 mL distilled water and 0.15 mL of 5 % sodium nitrate solution for 6 min. Then, 0.15 mL of 10% aluminum chloride solution was added to the mixture for 6 min. After that, 2 mL of sodium hydroxide (4%) was added to the mixture. The solution was made up to a total volume of 5 mL by adding distilled water, and it was left to stand for 15 min. The absorbance at 510 nm was determined using UV–Vis spectrophotometer (T60U, PG instruments ltd, UK). Results were calculated as quercetin equivalent (mg QE/100 g) of the sample using the standard curve, y = 0.004x + 0.0234.

#### 2.6.3. DPPH radical scavenging activity

The 2,2-diphenyl-2-picryl-hydrazyl (DPPH) radical scavenging assay was employed to assess the antioxidant activity of the extract [5]. Briefly, 2 mL of the methanol solution of the extract was mixed with 3 mL of a $6\times10^{-5}$ M methanol solution of DPPH in cuvettes. The mixtures were then left in the dark for 30 min. A change in color from purple to yellow indicated the progress of a reaction in a solution of DPPH that was recorded using a UV–Vis spectrophotometer (T60U, PG Instruments Limited, UK) at a wavelength of 517 nm ($A_1$). The absorbance of a control blank solution without the extract was recorded and noted. The sample's DPPH radical scavenging capacity was determined using Equation (10):

$$DPPH\ radical\ scavenging\ activity\ (\%) = \left[\frac{(A_0 - A_1)}{A_0}\right] \times 100 \quad (10)$$

where,$A_0$= the absorbance of control at initial time

$A_1$= the absorbance of sample.

The ability of the sample to scavenge the DPPH free radical was measured as an $EC_{50}$ value. The $EC_{50}$ values, expressed in mg/mL, were calculated from equation (10) and represented the amount of the sample required to prevent 50% of the DPPH radical scavenging activity. A graph of antioxidant properties (%) against sample concentration (mg/mL) were used to calculate the $EC_{50}$ value.

### 2.7. Determination of microbial load

The microbial count was used to determine the bacterial and fungal counts in dried samples. Rose Bengal Chloramphenicol agar (HiMedia, India) was used to determine the fungal load. The total bacterial count was done using standard plate count agar (Oxoid, UK). In 1 l of saline water, 18 g agar was dissolved. The sample (1 g) was poured into a test tube, previously filled with 9 mL of 0.89% autoclaved saline solution (0.89% NaCl). The bacterial and fungal counts were determined using the serial dilution approach. Each Petri dish with solidified agar media (20–25 mL) was inoculated with 100 μL of diluted solutions extracted from various materials. After inoculation, Petri plates were incubated at 37 and 30 °C, for bacteria and fungi, respectively in a laboratory incubator (IGS60, Thermo Fisher Science Inc., Germany). The incubated bacterial and fungal plates were allowed to grow for 24 and 72h, respectively. Finally, the bacterial and fungal count was done using a digital colony counter (BEXCO 220 V) [93].

### 2.8. Statistical analysis

All the experiments were conducted in triplicates and the results were presented as the average ± standard deviation, calculated using SPSS version 22.0 from Chicago, IL, USA. One-way analysis of variance (ANOVA) followed by Duncan's multiple range test (DMRT) was performed. The significance of the results was determined at a 95% confidence interval and considered significant if $p < 0.05$.

## 3. Results & discussion

### 3.1. Drying behavior of 'Taikor' slices

The fresh and pre-treated *Taikor* samples were dried at 50, 60, and 70 °C. The drying curves in Fig. 1 represent the drying characteristics of *Taikor* slices as moisture ratio (kg $H_2O$/kg dry mass) vs drying time (h). Drying times were found to vary depending on the type of pre-treatment used in conjunction with the temperature at which the product was dried. The drying time vs. moisture ratio curves indicate that the time needed to reach a safe moisture ratio varies greatly based on the pre-treatments and drying temperatures. Early in the drying process, the moisture removal rate was extremely high. More than 50% of the initial moisture was removed within the first 1h in all the cases. Following that, the rate greatly declined over time ($p<0.05$). It was observed from the drying curves that treated samples dried more quickly than untreated samples. Pretreatment-assisted drying showed a quicker drying time to reach the equilibrium state than the untreated samples. The increase in drying temperature from 50 to 60 °C sped up the drying process.

Figs 1**(a)–(c)** represent the effect of the osmotic pre-treatment on the moisture ratio of *Taikor* at a constant temperature of 50 °C and ultrasonic water bath pre-treatment in different time scales of 10, 20, and 30 min. There was constant decline in MR until 4h before became plateau until equilibrium moisture content was achieved. Then Figs 1**(d–f) and 1(f–h)** show the same analysis at 60 and 70 °C, respectively. In comparison to drying at 60 and 70, 50 °C required a longer drying time. At 70 °C, the moisture ratio became minimum withing 2–3h of drying operation. An imbalance in water vapor pressure was identified as one of the factors that accelerated drying because it led to a significant increase in moisture diffusivity at high temperatures, as reported by Methakhup et al. [57]. From Fig. 1, it was found that most of the time, fructose and sucrose samples showed better drying rate compared to the other samples. The fructose pre-treated samples dried more quickly when *Citrus macroptera* and *Garcinia pedunculata*, respectively, were dried in earlier experiments by Roy et al. [82] and Hossain et al. [39]. In a recent study, Rani and Tripathy [71] observed a reduction in the drying time from 10.5 to 8.0h when pineapple slices were osmotic pre-treated with potassium metabisulphite (KMS) solution. Trehalose pretreatment was also found to significantly shorten the drying time for several fruits [6]. The higher moisture diffusion rate may be the reason why osmotic pre-treatment significantly affected *Taikor*'s drying rate.

In Fig. 1, at 50 °C, water-treated samples showed a lower drying rate, but as the temperature rose from 60 to 70 °C drying rate increased for water pretreated samples as moisture content decreased gradually. Rahaman et al. [67] observed increased moisture reduction during ultrasound-assisted osmotic dehydration of plum fruits. The moisture content of ultrasound (US) assisted osmotic pre-treated dried saturn peaches was lower compared to the control sample [33]. Numerous investigations have reported similar behaviors, such as for pumpkins [54] and plums [67]. This procedure is connected to the cavitation brought on by US waves, which break down tissue cells and generate microscopic channels when combined with osmotic pressure. This increases the amount of water that leaves the fruit tissue and enters the osmotic solution [29]. Numerous additional elements influence moisture reduction, such as the duration of ultrasound exposure, voltage applied, food product composition, osmotic solution concentration, and solute concentration [58,8].

Sonication typically has a good effect on shortening the drying time used after osmotic treatment. For instance, it was observed that applying ultrasonication with and without an osmotic dehydration procedure

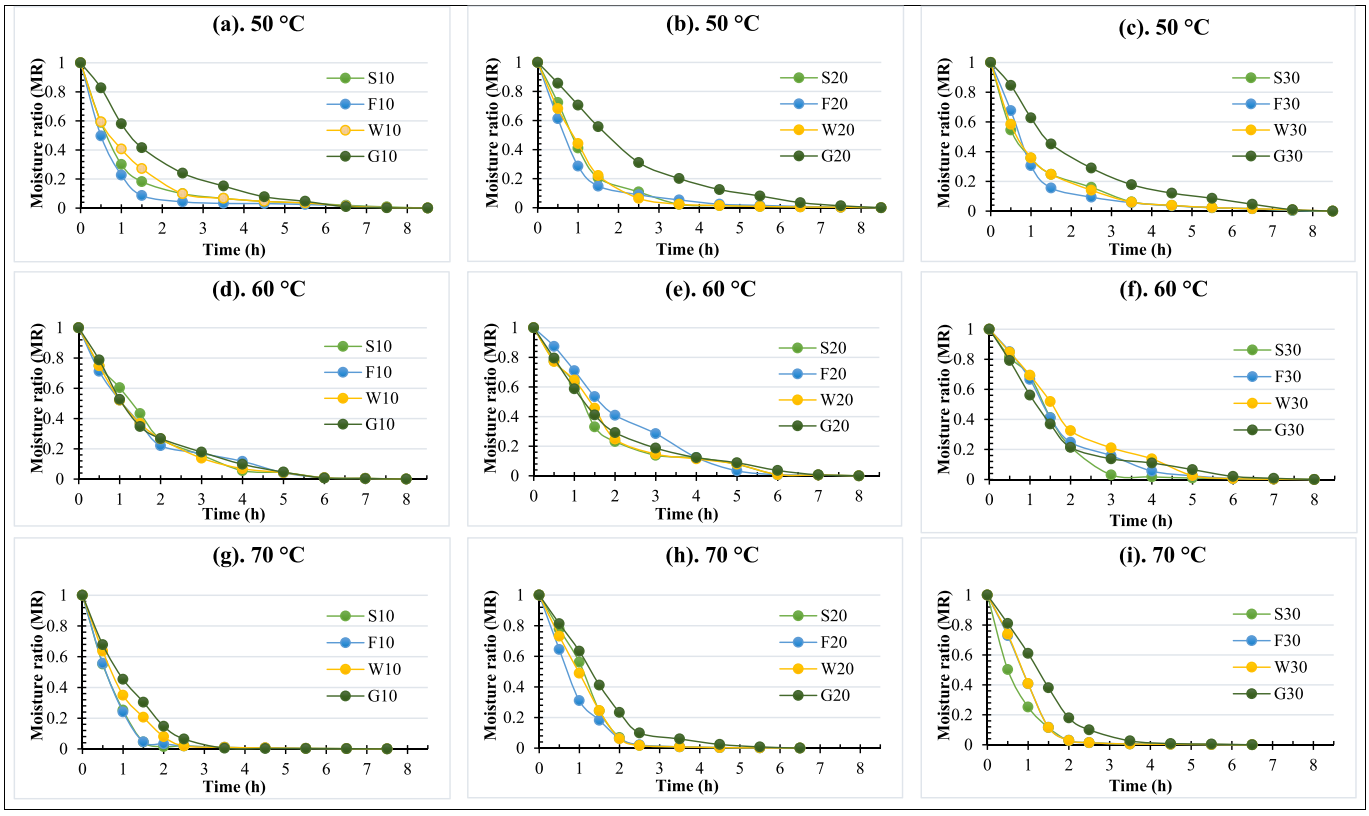


**Fig. 1.** Drying behavior of the osmotic and ultrasonic water bath pre-treated *Taikor* slices dried at 50 (a-c), 60 (d-f), and 70 °C (g-i) temperatures.

considerably sped up the drying process for pineapple [19]. Furthermore, Nowacka et al. [62] investigated the impact of the duration of ultrasound treatment (10, 20, 30, 45, and 90 min) in water and osmotic solution on water diffusivity, sugar loss, and water loss during papaya dehydration. They claimed that sonication reduces the drying time by around 16% and has a good impact on the effective diffusivity of water. The data also indicate that papayas lost 13.8% of their sugar content after 30 min of sonication, which can be used to develop low-sugar dried fruit snacks [62]. Numerous studies have found that ultrasound assisted osmotic dehydration followed by drying is a constructive approach because the osmotic dehydration process usually takes place before drying [58,8,62].

### 3.2. Fitting of mathematical models of Taikor slices for drying Kinetics

The four mathematical models, such as the Page model, Newton's (Exponential) model, Henderson and Pabis' model, and Weibull's distribution model were used to describe the drying process of *Taikor* slices. The highest determination coefficient ($R^2$) value and the lowest root mean square error (RMSE), sum squared error (SSE), and mean square of the deviation ($\chi^2$) values for modelling were used to select the best model (Table 2**)**. According to Table 2, the determination coefficient ($R^2$) values for the Page model ranged from 0.9824 to 0.9978, while values for Newton's model ranged from 0.1025 to 0.3965, for Henderson and Pabis' model from 0.0124 to 0.8542, and for Weibull distribution's model from 0.9205 to 0.9876. The root mean square error (RMSE) values for Page, Newton, Henderson and Pabis', and Weibull models ranged from 0.1120 to 0.1776, 0.1420 to 0.7586, 0.1896 to 0.9865, and 0.1147 to 0.1975, respectively. The chi-square values for Page, Henderson and Pabis', Newton's, and Weibull's models, respectively, ranged from 0.0128 to 0.0317, 0.1730 to 0.9738, 0.0207 to 0.5760, and 0.0138 to 0.0399. The sum square error (SSE) values for Page, Newton, Henderson and Pabis', and Weibull models, respectively, ranged from 0.0125 to 0.0315, 0.0320 to 0.5755, 0.1724 to 0.9732, and 0.0131 to 0.0389.

The model with the best goodness of fit should have the highest $R^2$ and lowest $\chi^2$, SSE, and RMSE values [31]. Both the Page and the Weibull models correctly predicted the drying behavior of *Taikor* slices. However, when all the parameters were considered, the Page model was the best-fitted model. In earlier investigations on purple-fleshed sweet potatoes [56] and asparagus roots [50], the Page model was validated as an appropriate drying model to predict the moisture data. According to Rashid et al. [72], the Page model accurately describes the drying process of US and osmotic pretreated sweet potatoes. In a separate study, Hossain et al. [39] found the Page model as the best-fitted model to predict the experimental MR for osmotic pre-treated dried *Garcinia pedunculata*. Similar results were reported in the literature on the application of the Page model to characterize the drying qualities of foodstuffs for purslane [46], sour-cherry [24], tomatoes [23], pineapple (Ramallo & Mascheroni, 2012a), mango [22], and *C. macroptera* [82]. These findings underscore the importance of utilizing appropriate mathematical models for understanding the complex mechanisms involved in food drying.

### 3.3. Changes in color

Table 3 presents the color values of fresh and all dried samples. Color has been identified as one of the most important quality parameters of dry products. From Table 3, the lightness value dropped as the drying temperature increased. The fresh sample's surface color had the maximum L* value (43.72±0.03), whereas the lowest (33.79±0.12) was in glucose-treated samples dried at 70 °C. The accelerated non-enzymatic browning reactions at high temperatures might be the major cause of reduced L* values at elevated temperatures. This considerable browning reactivity and accelerated crust growth may be caused by exposure to high temperatures, as suggested by many previous studies [25,84,14]. The redness/greenness parameter a* and the yellowness/blueness index b* of the samples increase with drying

**Table 2**
$R^2$, RMSE, $\chi^2$, and SSE values for four different models at 50, 60 and 70 °C drying temperature.

| Drying Temperature | Pre-treatment | Page Model (K) | | | | Henderson & Pabis' Model (a) | | | | Newton's Model (n) | | | | Weibull distribution | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $R^2$ | *RMSE* | $\chi^2$ | SSE | $R^2$ | *RMSE* | $\chi^2$ | SSE | $R^2$ | *RMSE* | $\chi^2$ | SSE | $R^2$ | *RMSE* | $\chi^2$ | SSE |
| | **S10** | 0.9867 | 0.1142 | 0.0136 | 0.0130 | 0.3256 | 0.5472 | 0.2998 | 0.2994 | 0.1574 | 0.2564 | 0.0660 | 0.0657 | 0.9366 | 0.1277 | 0.0170 | 0.0163 |
| | **F10** | 0.9866 | 0.1147 | 0.0138 | 0.0131 | 0.0145 | 0.6824 | 0.4659 | 0.4657 | 0.3678 | 0.3472 | 0.1211 | 0.1205 | 0.9398 | 0.1684 | 0.0295 | 0.0283 |
| **Drying** | **W10** | 0.9862 | 0.1174 | 0.0139 | 0.0138 | 0.3689 | 0.5718 | 0.3276 | 0.3270 | 0.1498 | 0.4863 | 0.2371 | 0.2365 | 0.9398 | 0.1875 | 0.0358 | 0.0351 |
| **at 50 °C** | **G10** | 0.9865 | 0.1196 | 0.0153 | 0.0143 | 0.2610 | 0.7584 | 0.5756 | 0.5752 | 0.2582 | 0.2485 | 0.0620 | 0.0617 | 0.9205 | 0.1482 | 0.0230 | 0.0221 |
| | **S20** | 0.9865 | 0.1139 | 0.0131 | 0.0129 | 0.4589 | 0.8596 | 0.7391 | 0.7389 | 0.3748 | 0.1458 | 0.0217 | 0.0212 | 0.9653 | 0.1354 | 0.0190 | 0.0183 |
| | **F20** | 0.9865 | 0.1147 | 0.0138 | 0.0131 | 0.1477 | 0.7421 | 0.5511 | 0.5508 | 0.2478 | 0.1586 | 0.0256 | 0.0251 | 0.9654 | 0.1284 | 0.0177 | 0.0164 |
| | **W20** | 0.9862 | 0.1198 | 0.0151 | 0.0143 | 0.1456 | 0.6689 | 0.4478 | 0.4474 | 0.2436 | 0.1758 | 0.0312 | 0.0309 | 0.9368 | 0.1473 | 0.0222 | 0.0217 |
| | **G20** | 0.9824 | 0.1169 | 0.0140 | 0.0136 | 0.3569 | 0.7586 | 0.5756 | 0.5755 | 0.1875 | 0.5422 | 0.2947 | 0.2940 | 0.9658 | 0.1196 | 0.0152 | 0.0143 |
| | **S30** | 0.9866 | 0.1147 | 0.0139 | 0.0131 | 0.0124 | 0.8695 | 0.7565 | 0.7561 | 0.1748 | 0.4566 | 0.2090 | 0.2085 | 0.9676 | 0.1358 | 0.0192 | 0.0184 |
| | **F30** | 0.9860 | 0.1120 | 0.0128 | 0.0125 | 0.6458 | 0.8249 | 0.6807 | 0.6805 | 0.2489 | 0.3511 | 0.1238 | 0.1232 | 0.9635 | 0.1924 | 0.0377 | 0.0370 |
| | **W30** | 0.9865 | 0.1175 | 0.0143 | 0.0138 | 0.3354 | 0.7184 | 0.5166 | 0.5161 | 0.2635 | 0.3674 | 0.1355 | 0.1350 | 0.9668 | 0.1147 | 0.0138 | 0.0131 |
| | **G30** | 0.9863 | 0.1198 | 0.0150 | 0.0143 | 0.2928 | 0.5674 | 0.3224 | 0.3220 | 0.2147 | 0.2459 | 0.0613 | 0.0605 | 0.9665 | 0.1975 | 0.0399 | 0.0390 |
| | **Average** | 0.9861 | 0.1165 | 0.0143 | 0.0146 | 0.2813 | 0.7143 | 0.5223 | 0.5214 | 0.2413 | 0.3153 | 0.1126 | 0.1153 | 0.9531 | 0.1506 | 0.0247 | 0.0234 |
| | **±SD** | ±0.01 | ±0.0171 | ±0.0032 | ±0.0026 | ±0.1819 | ±0.1132 | ±0.1618 | ±0.1635 | ±0.0738 | ±0.1325 | ±0.0937 | ±0.0933 | ±0.0236 | ±0.0369 | ±0.0154 | ±0.0117 |
| | **S10** | 0.9862 | 0.1147 | 0.0138 | 0.0131 | 0.3793 | 0.5806 | 0.3375 | 0.3371 | 0.1789 | 0.1789 | 0.0325 | 0.0320 | 0.9675 | 0.1739 | 0.0311 | 0.0302 |
| | **F10** | 0.9863 | 0.1168 | 0.0138 | 0.0136 | 0.7352 | 0.5456 | 0.2980 | 0.2977 | 0.1475 | 0.4211 | 0.1779 | 0.1773 | 0.9689 | 0.1835 | 0.0340 | 0.0337 |
| **Drying** | **W10** | 0.9866 | 0.1148 | 0.0139 | 0.0131 | 0.3548 | 0.7681 | 0.5910 | 0.5900 | 0.3478 | 0.3458 | 0.1199 | 0.1196 | 0.9674 | 0.1836 | 0.0341 | 0.0337 |
| **at 60 °C** | **G10** | 0.9867 | 0.1145 | 0.0139 | 0.0131 | 0.2896 | 0.5842 | 0.3418 | 0.3413 | 0.1424 | 0.2644 | 0.0701 | 0.0699 | 0.9636 | 0.1257 | 0.0162 | 0.0158 |
| | **S20** | 0.9862 | 0.1274 | 0.0168 | 0.0162 | 0.3544 | 0.4877 | 0.2381 | 0.2378 | 0.1397 | 0.4583 | 0.2109 | 0.2100 | 0.9784 | 0.1458 | 0.0222 | 0.0212 |
| | **F20** | 0.9895 | 0.1244 | 0.0159 | 0.0154 | 0.4657 | 0.4592 | 0.2116 | 0.2108 | 0.1496 | 0.3556 | 0.1272 | 0.1265 | 0.9748 | 0.1298 | 0.0174 | 0.0168 |
| | **W20** | 0.9892 | 0.1292 | 0.0169 | 0.0167 | 0.2284 | 0.7458 | 0.5572 | 0.5562 | 0.2766 | 0.1420 | 0.0207 | 0.0201 | 0.9768 | 0.1748 | 0.0311 | 0.0305 |
| | **G20** | 0.9891 | 0.1274 | 0.0167 | 0.0162 | 0.0328 | 0.1896 | 0.0361 | 0.0359 | 0.2745 | 0.2609 | 0.0688 | 0.0681 | 0.9748 | 0.1974 | 0.0399 | 0.0389 |
| | **S30** | 0.9896 | 0.1347 | 0.0183 | 0.0181 | 0.6751 | 0.4152 | 0.1730 | 0.1724 | 0.1983 | 0.4755 | 0.2269 | 0.2261 | 0.9789 | 0.1784 | 0.0322 | 0.0318 |
| | **F30** | 0.9894 | 0.1274 | 0.0167 | 0.0162 | 0.5574 | 0.5874 | 0.3458 | 0.3451 | 0.3149 | 0.3678 | 0.1357 | 0.1353 | 0.9784 | 0.1485 | 0.0227 | 0.0220 |
| | **W30** | 0.9892 | 0.1247 | 0.0159 | 0.0155 | 0.3456 | 0.4583 | 0.2110 | 0.2100 | 0.1449 | 0.1452 | 0.0216 | 0.0210 | 0.9786 | 0.1506 | 0.0233 | 0.0227 |
| | **G30** | 0.9897 | 0.1255 | 0.0161 | 0.0157 | 0.4963 | 0.6852 | 0.4699 | 0.4695 | 0.2763 | 0.2365 | 0.0563 | 0.0559 | 0.9748 | 0.1142 | 0.0139 | 0.0130 |
| | **Average** | 0.9883 | 0.124 | 0.0166 | 0.0152 | 0.4097 | 0.5427 | 0.3182 | 0.3172 | 0.2162 | 0.3042 | 0.1062 | 0.1051 | 0.9741 | 0.1594 | 0.0263 | 0.0266 |
| | **±SD** | ±0.0117 | ±0.0165 | ±0.0016 | ±0.0009 | ±0.1921 | ±0.1641 | ±0.1636 | ±0.1651 | ±0.0735 | ±0.1234 | ±0.07 | ±0.0738 | ±0.0542 | ±0.0326 | ±0.0122 | ±0.0019 |
| | **S10** | 0.9910 | 0.1472 | 0.0221 | 0.0216 | 0.6952 | 0.4852 | 0.2360 | 0.2354 | 0.2499 | 0.2499 | 0.0633 | 0.0624 | 0.9786 | 0.1740 | 0.0308 | 0.0302 |
| | **F10** | 0.9914 | 0.1398 | 0.0198 | 0.0195 | 0.4758 | 0.8546 | 0.7308 | 0.7303 | 0.3452 | 0.3782 | 0.1433 | 0.1430 | 0.9741 | 0.1236 | 0.0163 | 0.0152 |
| **Drying** | **W10** | 0.9968 | 0.1472 | 0.0224 | 0.0216 | 0.6355 | 0.4157 | 0.1730 | 0.1728 | 0.3965 | 0.2415 | 0.0590 | 0.0583 | 0.9768 | 0.1472 | 0.0224 | 0.0216 |
| **at 70 °C** | **G10** | 0.9978 | 0.1398 | 0.0199 | 0.0195 | 0.2569 | 0.6895 | 0.4758 | 0.4754 | 0.2749 | 0.2455 | 0.0611 | 0.0603 | 0.9725 | 0.1548 | 0.0241 | 0.0239 |
| | **S20** | 0.9912 | 0.1247 | 0.0159 | 0.0155 | 0.2455 | 0.7422 | 0.5511 | 0.5509 | 0.1965 | 0.3489 | 0.1221 | 0.1217 | 0.9869 | 0.1963 | 0.0391 | 0.0385 |
| | **F20** | 0.9935 | 0.1777 | 0.0317 | 0.0315 | 0.2245 | 0.9863 | 0.9730 | 0.9728 | 0.1798 | 0.7586 | 0.5760 | 0.5755 | 0.9838 | 0.1887 | 0.0360 | 0.0356 |
| | **W20** | 0.9912 | 0.1748 | 0.0307 | 0.0305 | 0.4183 | 0.7852 | 0.6170 | 0.6165 | 0.2486 | 0.3684 | 0.1362 | 0.1357 | 0.9849 | 0.1932 | 0.0385 | 0.0373 |
| | **G20** | 0.9965 | 0.1422 | 0.0206 | 0.0202 | 0.1358 | 0.8452 | 0.7150 | 0.7143 | 0.3418 | 0.3589 | 0.1293 | 0.1288 | 0.9874 | 0.1498 | 0.0230 | 0.0224 |
| | **S30** | 0.9947 | 0.1247 | 0.0157 | 0.0155 | 0.5688 | 0.4711 | 0.2221 | 0.2219 | 0.3644 | 0.6899 | 0.4768 | 0.4760 | 0.9876 | 0.1478 | 0.0221 | 0.0218 |
| | **F30** | 0.9964 | 0.1258 | 0.0159 | 0.0158 | 0.8542 | 0.6892 | 0.4755 | 0.4750 | 0.1025 | 0.2445 | 0.0600 | 0.0598 | 0.9835 | 0.1659 | 0.0283 | 0.0275 |
| | **W30** | 0.9948 | 0.1695 | 0.0290 | 0.0287 | 0.4392 | 0.7845 | 0.6160 | 0.6154 | 0.3677 | 0.3999 | 0.1600 | 0.1599 | 0.9867 | 0.1420 | 0.0209 | 0.0201 |
| | **G30** | 0.9926 | 0.1745 | 0.0305 | 0.0304 | 0.1482 | 0.9865 | 0.9738 | 0.9732 | 0.2541 | 0.3985 | 0.1592 | 0.1587 | 0.9863 | 0.1754 | 0.0311 | 0.0307 |
| | **Average** | 0.9937 | 0.1493 | 0.0235 | 0.0232 | 0.4258 | 0.7282 | 0.5623 | 0.5637 | 0.2774 | 0.3901 | 0.1791 | 0.1788 | 0.9821 | 0.1635 | 0.0282 | 0.0274 |
| | **±SD** | ±0.0113 | ±0.0201 | ±0.0012 | ±0.0121 | ±0.2312 | ±0.1919 | ±0.2713 | ±0.2741 | ±0.0951 | ±0.1745 | ±0.1723 | ±0.1781 | ±0.0152 | ±0.0232 | ±0.0143 | ±0.0112 |

**Table 3**
Color values of fresh and pretreated dried *Taikor* slices.

| Drying Temperature | Sample | L* | a* | b* | Chroma | Hue Angle | ΔE |
|---|---|---|---|---|---|---|---|
| | Fresh | 43.72 ± 0.03$^{b}$ | 4.08 ± 0.12 $^{h}$ | 18.08 ± 0.17$^{a}$ | 18.53 ± 0.32$^{b}$ | 77.28 ± 0.18$^{a}$ | — |
| | S10 | 42.00 ± 0.10$^{c}$ | 7.92 ± 0.23$^{a}$ | 15.91 ± 0.21$^{d}$ | 17.47 ± 0.11$^{c}$ | 65.58 ± 0.13 $^{h}$ | 12.01 ± 0.14 $^{l}$ |
| | F10 | 45.00 ± 0.21$^{a}$ | 8.88 ± 0.11$^{a}$ | 18.03 ± 0.28$^{a}$ | 20.00 ± 0.15$^{a}$ | 63.77 ± 0.15$^{i}$ | 8.75 ± 0.18$^{n}$ |
| | W10 | 40.00 ± 0.23$^{e}$ | 8.43 ± 0.25$^{a}$ | 17.04 ± 0.11$^{b}$ | 19.01 ± 0.17$^{b}$ | 63.67 ± 0.22$^{i}$ | 13.12 ± 0.31 $^{k}$ |
| **50 °C** | G10 | 41.00 ± 0.15 $^{g}$ | 6.24 ± 0.13$^{c}$ | 14.14 ± 0.20$^{e}$ | 15.45 ± 0.10$^{e}$ | 66.18 ± 1.03 $^{g}$ | 27.58 ± 0.58$^{d}$ |
| | S20 | 46.40 ± 0.12$^{a}$ | 8.38 ± 0.13$^{a}$ | 16.99 ± 0.15$^{b}$ | 18.95 ± 0.23$^{b}$ | 63.74 ± 0.26$^{i}$ | 8.89 ± 0.30$^{n}$ |
| | F20 | 45.00 ± 0.3$^{a}$ | 6.86 ± 0.22$^{c}$ | 16.94 ± 0.25$^{b}$ | 18.27 ± 0.28$^{b}$ | 67.94 ± 0.28$^{f}$ | 6.33 ± 0.18$^{o}$ |
| | W20 | 41.04 ± 0.11$^{d}$ | 7.73 ± 0.15$^{a}$ | 17.45 ± 0.31$^{b}$ | 19.09 ± 0.14$^{b}$ | 66.10 ± 0.21$^{gh}$ | 11.93 ± 0.61 $^{l}$ |
| | G20 | 44.31 ± 0.12$^{b}$ | 7.05 ± 0.10$^{b}$ | 15.21 ± 0.11$^{d}$ | 16.76 ± 0.10$^{d}$ | 65.13 ± 0.42$^{j}$ | 17.52 ± 0.96 $^{g}$ |
| | S30 | 44.40 ± 0.12$^{b}$ | 7.08 ± 0.17$^{b}$ | 16.16 ± 0.19$^{c}$ | 17.64 ± 0.11$^{c}$ | 66.35 ± 0.28 $^{g}$ | 10.11 ± 0.19 $^{m}$ |
| | F30 | 44.70 ± 0.18$^{b}$ | 8.12 ± 0.12$^{a}$ | 19.48 ± 0.08$^{a}$ | 21.51 ± 0.24$^{a}$ | 64.90 ± 0.30 $^{h}$ | 8.20 ± 0.11$^{n}$ |
| | W30 | 44.11 ± 0.24$^{b}$ | 7.05 ± 0.25$^{b}$ | 16.03 ± 0.26$^{c}$ | 17.51 ± 0.29$^{c}$ | 66.27 ± 0.41$^{gh}$ | 7.55 ± 0.18$^{f}$ |
| | G30 | 44.18 ± 0.10$^{b}$ | 7.19 ± 0.26$^{b}$ | 15.97 ± 0.19$^{d}$ | 15.97 ± 0.14$^{d}$ | 65.76 ± 0.22$^{gh}$ | 14.08 ± 1.17$^{hij}$ |
| | S10 | 40.96 ± 0.08$^{e}$ | 5.30 ± 0.23$^{d}$ | 12.84 ± 0.21$^{f}$ | 13.89 ± 0.11$^{f}$ | 67.57 ± 0.13 $^{h}$ | 14.86 ± 0.14$^{hi}$ |
| | F10 | 43.80 ± 0.13$^{b}$ | 6.90 ± 0.11$^{b}$ | 17.17 ± 0.28$^{b}$ | 18.50 ± 0.15$^{b}$ | 68.10 ± 0.15$^{f}$ | 9.80 ± 0.18 $^{m}$ |
| | W10 | 39.40 ± 0.29$^{f}$ | 7.29 ± 0.25$^{b}$ | 16.35 ± 0.11$^{c}$ | 17.90 ± 0.17$^{c}$ | 65.96 ± 0.22 $^{h}$ | 13.84 ± 0.31 $^{k}$ |
| **60 °C** | G10 | 38.55 ± 0.06 $^{g}$ | 3.97 ± 0.33$^{ef}$ | 15.14 ± 0.11$^{d}$ | 15.65 ± 0.58$^{e}$ | 75.30 ± 0.88$^{ab}$ | 35.38 ± 0.79$^{b}$ |
| | S20 | 40.91 ± 0.23$^{e}$ | 6.20 ± 0.13$^{c}$ | 14.84 ± 0.15$^{c}$ | 16.08 ± 0.23$^{d}$ | 67.32 ± 0.26 $^{g}$ | 12.05 ± 0.30 $^{l}$ |
| | F20 | 42.18 ± 0.33$^{c}$ | 5.34 ± 0.22$^{d}$ | 15.90 ± 0.25$^{d}$ | 16.77 ± 0.28$^{d}$ | 71.43 ± 0.28$^{e}$ | 11.86 ± 0.18 $^{l}$ |
| | W20 | 40.00 ± 0.12$^{e}$ | 6.95 ± 0.15$^{b}$ | 17.00 ± 0.31$^{b}$ | 18.36 ± 0.14$^{b}$ | 67.76 ± 0.21 $^{g}$ | 12.97 ± 0.61 $^{k}$ |
| | G20 | 40.10 ± 0.25$^{e}$ | 4.19 ± 0.11$^{e}$ | 15.82 ± 0.20$^{d}$ | 16.36 ± 0.18$^{d}$ | 75.15 ± 0.52$^{ab}$ | 28.32 ± 0.51$^{d}$ |
| | S30 | 40.02 ± 0.24$^{e}$ | 5.10 ± 0.17$^{d}$ | 13.09 ± 0.19$^{f}$ | 14.04 ± 0.11$^{f}$ | 68.71 ± 0.28$^{f}$ | 15.36 ± 0.19 $^{h}$ |
| | F30 | 43.19 ± 0.21 $^{l}$ | 8.14 ± 0.12$^{e}$ | 18.30 ± 0.08$^{b}$ | 20.02 ± 0.24$^{a}$ | 66.02 ± 0.30 $^{g}$ | 9.76 ± 0.11 $^{m}$ |
| | W30 | 43.00 ± 0.10 $^{g}$ | 6.83 ± 0.25$^{b}$ | 15.10 ± 0.26$^{d}$ | 16.57 ± 0.29$^{d}$ | 65.66 ± 0.41 $^{h}$ | 11.81 ± 0.18 $^{l}$ |
| | G30 | 41.17 ± 0.26$^{d}$ | 4.87 ± 0.15$^{e}$ | 16.11 ± 0.13$^{c}$ | 16.83 ± 0.21$^{d}$ | 73.18 ± 0.08$^{d}$ | 19.72 ± 0.26$^{f}$ |
| | S10 | 36.17 ± 0.13 $^{h}$ | 2.90 ± 0.20 $^{g}$ | 10.30 ± 0.31 $^{g}$ | 10.70 ± 0.21$^{i}$ | 74.27 ± 0.10$^{c}$ | 20.30 ± 0.14$^{e}$ |
| | F10 | 39.90 ± 0.28$^{f}$ | 3.80 ± 0.10$^{f}$ | 13.03 ± 0.08$^{f}$ | 13.57 ± 0.5 $^{l}$ | 73.74 ± 0.12$^{d}$ | 15.63 ± 0.18 $^{h}$ |
| | W10 | 35.30 ± 0.23$^{i}$ | 4.00 ± 0.35$^{e}$ | 13.30 ± 0.10$^{f}$ | 13.88 ± 0.18$^{f}$ | 73.26 ± 0.32$^{d}$ | 19.02 ± 0.31$^{f}$ |
| **70 °C** | G10 | 37.13 ± 0.13$^{d}$ | 3.64 ± 0.10$^{f}$ | 12.56 ± 0.21 $^{h}$ | 9.81 ± 0.28$^{j}$ | 74.39 ± 0.86$^{bc}$ | 32.38 ± 0.19$^{c}$ |
| | S20 | 34.09 ± 0.22$^{i}$ | 3.08 ± 0.23$^{f}$ | 9.80 ± 0.14 $^{h}$ | 10.27 ± 0.13$^{j}$ | 72.55 ± 0.36$^{e}$ | 22.16 ± 0.30$^{e}$ |
| | F20 | 38.30 ± 0.03 $^{g}$ | 2.12 ± 0.12 $^{h}$ | 12.84 ± 0.15$^{f}$ | 13.04 ± 0.28 $^{g}$ | 75.93 ± 0.18$^{b}$ | 17.21 ± 0.18 $^{g}$ |
| | W20 | 37.17 ± 0.11 $^{h}$ | 2.92 ± 0.17 $^{g}$ | 14.48 ± 0.21$^{e}$ | 14.77 ± 0.34$^{f}$ | 78.59 ± 0.22$^{a}$ | 16.99 ± 0.61 $^{g}$ |
| | G20 | 33.79 ± 0.12$^{j}$ | 2.98 ± 0.33 $^{g}$ | 10.20 ± 0.40$^{gh}$ | 10.62 ± 0.44$^{i}$ | 73.71 ± 0.70$^{d}$ | 36.91 ± 0.99$^{b}$ |
| | S30 | 37.14 ± 0.12 $^{h}$ | 2.87 ± 0.28 $^{g}$ | 10.84 ± 0.39 $^{g}$ | 11.21 ± 0.31$^{i}$ | 75.17 ± 0.24$^{b}$ | 19.24 ± 0.19$^{f}$ |
| | F30 | 39.00 ± 0.28$^{f}$ | 5.02 ± 0.20$^{d}$ | 16.05 ± 0.29$^{c}$ | 16.18 ± 0.22$^{d}$ | 72.63 ± 0.30$^{e}$ | 14.34 ± 0.11$^{j}$ |
| | W30 | 39.18 ± 0.14$^{f}$ | 3.10 ± 0.15$^{f}$ | 11.14 ± 0.46 $^{g}$ | 11.56 ± 0.26$^{i}$ | 74.43 ± 0.48$^{bc}$ | 17.56 ± 0.18 $^{g}$ |
| | G30 | 34.54 ± 0.10$^{i}$ | 3.14 ± 0.18$^{d}$ | 11.63 ± 0.33 $^{g}$ | 12.04 ± 0.56 $^{h}$ | 74.89 ± 0.88$^{bc}$ | 39.72 ± 0.43$^{a}$ |

*The values with the different superscripts in the same column are significantly different from each other.

temperature. The highest a* (9.12±0.12) and b* (19.48±0.08) values were found in samples US treated in only water and dried at 50 °C. This finding is nearly equivalent to the results obtained from drying of *Taikor* and pineapple slices in previous studies by Hossain et al. (2021) and Zzaman et al. [93], respectively. In a previous study, Garcia-Noguera et al. [30] found that osmotic dehydration improves the color retention of strawberries during drying when assisted with US pretreatment. Chroma is the degree to which a color differs from an utterly grayscale image. It reaches the highest possible level of a pure color. The chroma value of a color is how bright and pure it is. Higher chroma values were associated with lower drying temperatures, meaning that lower drying temperatures had less impact on chroma values and thus preserved color purity. In this case, sample F30 showed the highest chroma value (21.51 ±0.24) when dried at 50 °C. Hue is an essential analytical tool for characterizing color because it reveals how red, yellow, green, or blue a product is, among other attributes. The hue values are measured in the range of 0 to 360°, where 0, 90, 180, and 270° reflect pure red, yellow, green, and blue colors [70]. Customers use this parameter to decide whether a product is acceptable [12]. It is evident from the findings of the study that elevated drying temperatures and prolonged ultrasonic pretreatment durations invariably resulted in a rise in hue angle values. The total color change (ΔE) increased with drying temperature, which concludes that high drying temperature has a higher impact on color change. The total color change also increased with the ultrasound treatment time. However, this change shows variability with the types of sugar solution. Overall, fructose showed the lowest change in color, and glucose solution exhibited the highest color change. The colorimetric indices were also affected when osmotic solutions like sugar solution were used instead of distilled water ($p < 0.05$). Changes in the color index may be influenced by the colorful pigments of osmotic solutions, which can occur as a result of chemical processes like the Milliard reaction between sugar and protein or the formation of melanoidin. According to Aadil et al. [1], glucose and fructose have a more significant role in the synthesis and interactions of color pigments due to their chemical composition.

### 3.4. Effect of pretreatment on bioactive compounds

#### 3.4.1. Impact on ascorbic acid (Vitamin C)

One of the most important indicators of the nutritional value of a dried food sample is believed to be vitamin C, also known as ascorbic acid. Vitamin C is sensitive to light and heat. In addition to quickly leaching out, it can be depleted when the moisture content of a food evaporates at high temperatures [80]. The fresh *Taikor* sample had the highest ascorbic acid concentration (147.68 ± 0.19 mg/100 g) (Fig. 2). It was reduced in samples treated at elevated drying temperatures from 50 °C to 70 °C. The maximum amount (130.40 ± 0.51 mg/100 g) of ascorbic acid was found in glucose-treated *Garcinia pedunculata* dried at 50 °C. In contrast, the minimum concentration (82.89±0.78 mg/100 g) of vitamin C was found in fructose-treated *Garcinia pedunculata* dried at 70 °C. It was found that the samples with longer ultrasonic and osmotic pretreatment had slightly lower values of ascorbic acid content than short-time treatments. Ascorbic acid may be lost through leaching when Taikor is absorbed in the osmotic solution, as it is a water-soluble vitamin [82]. Furthermore, it is most likely that vitamin C was lost during drying due to the presence of the ascorbic acid oxidase enzyme,

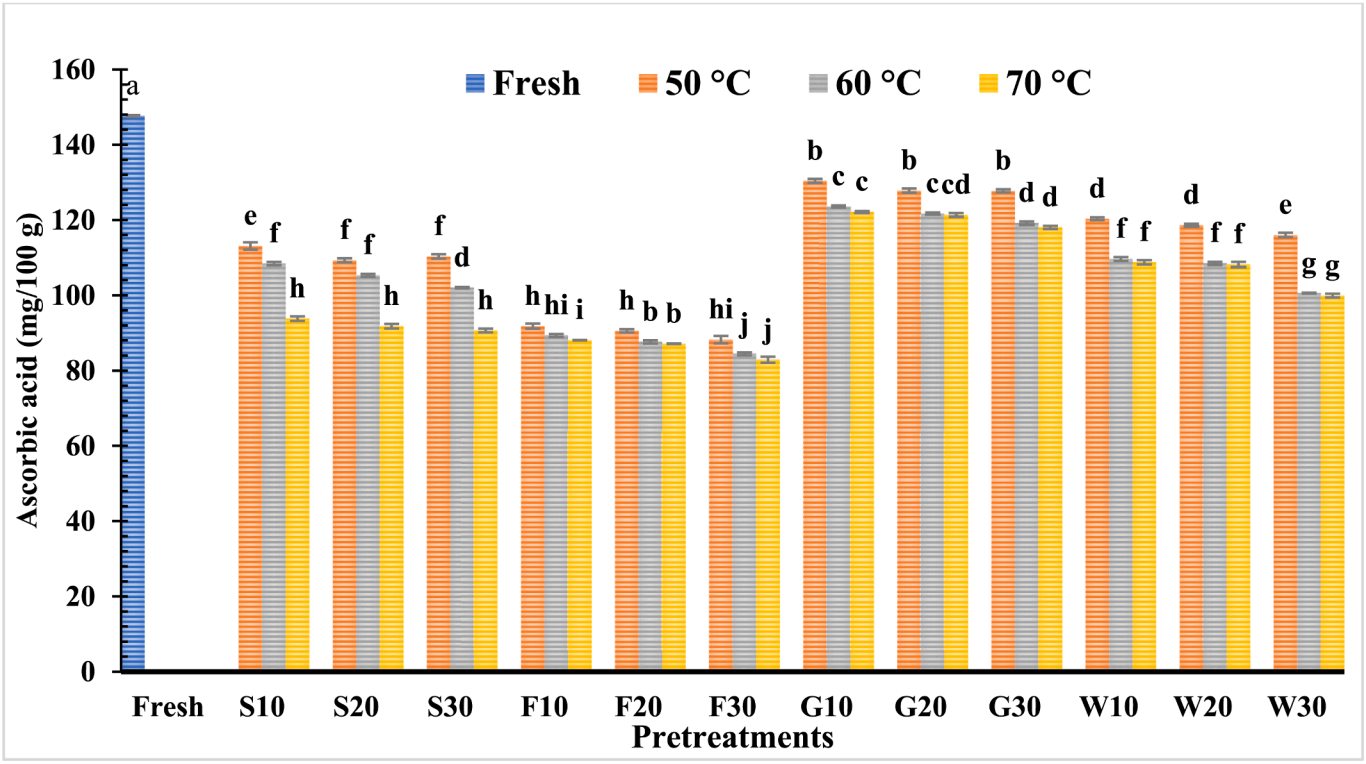


**Fig. 2.** Ascorbic acid (Vitamin C) of *Taikor* samples dried at 50, 60 and 70 °C.

which catalyzes the oxidation of vitamin C for breakdown [60]. Previously, the osmotic pretreated tomato samples were found to retain the most vitamin C, and this was because of the proliferating coating on the cut surface of the sample [37].

### 3.4.2. *Impact on β-Carotene (Vitamin A)*

Fig. 3 exhibits the results of β-carotene content in osmotic and ultrasound treated dried *Taikor* samples. β-carotene is a type of hydrocarbon carotenoid that can be converted into vitamin A in the human body, as stated by Hiranvarachat et al. [36]. A fresh *Taikor* sample has the highest (46± 0.22 mg/100 g) level of β-carotene. The maximum reduction (19.47±0.39 mg/100 g) of β-carotene was identified in sucrose-treated *Garcinia pedunculata* dried at 70 °C, whereas the minimum reduction (39.49±0.33 mg/100 g) was reported in glucose-treated

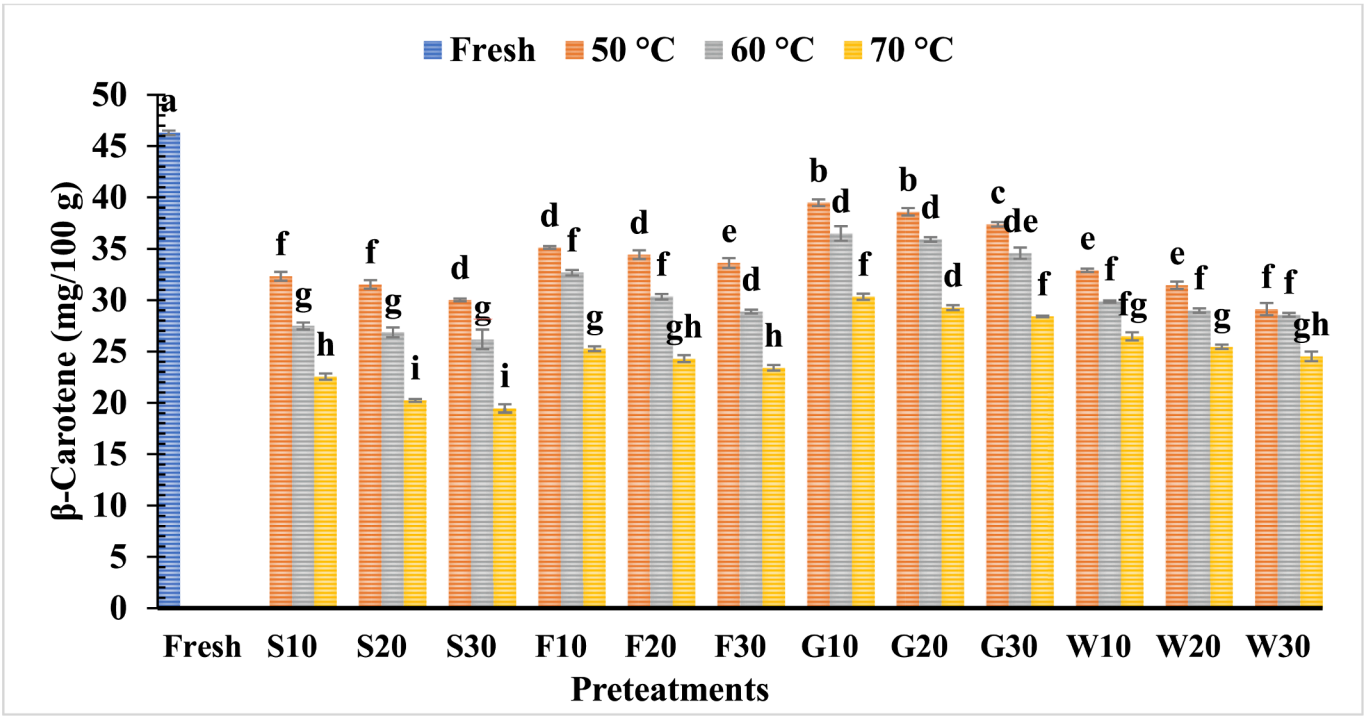


**Fig. 3.** β-Carotene (vitamin A) of fresh and pretreated *Taikor* samples dried at different temperatures.

*Garcinia pedunculata* dried at 50 °C. Because β-carotene is insoluble in water, it was kept for all the *Garcinia pedunculata* samples' pre-treatments. According to a previous study, Fernandes et al. [27] also observed a drop in β-carotene concentration in ultrasound-assisted dried apples. Even though Vitamin A is protected from oxidation within the fruit's lipid matrix because of the presence of vitamin E and other antioxidants, the degradation of vitamin A can occur due to prolonged exposure to ultrasound. Since vitamin E has a low retention rate, it was unable to exert its protective function on vitamin A (Fernandes et al., 2015). Furthermore, when the drying temperature was increased from 50 to 70 °C, the vitamin C content in the treated samples decreased. This is due to the fact that ascorbic acid is susceptible to degradation from heat, oxygen, light, and enzymes [51].

### 3.4.3. Impact on B vitamins

The quantities of B vitamins in treated *Taikor* samples, such as thiamine hydrochloride ($B_1$), riboflavin ($B_2$), nicotinamide ($B_3$), and pyridoxine ($B_6$) contents are shown in Table 4. The concentration of different B vitamins in fresh samples were 3.75±0.45 mg/g ($B_1$), 2.10±0.11 mg/g ($B_2$), 1.42±0.19 mg/g ($B_3$), and 1.01±0.11 mg/g ($B_6$). The B vitamins are known as water-soluble vitamins. Hence, it was crucial to determine if any B vitamins were lost during the dipping pre-treatment process in this study.

Table 4 shows that the amounts of vitamins $B_1$, $B_2$, $B_3$, and $B_5$ gradually decreased at higher drying temperatures. According to research conducted by Kadakal et al. [44], thiamin (also known as vitamin $B_1$) is highly sensitive to heat and can be described using first-order kinetic reactions. In this study, thiamin content was reduced from 3.75 mg/g in fresh sample to 0.72 mg/g for sucrose pretreated sample dried at 70 °C. The increase in temperature was observed to result in the reduction of Vitamin $B_2$, $B_3$, and $B_6$. This reduction of B vitamins in fresh fruit samples after drying has been supported by multiple prior studies [28,93,40]. Vitamins $B_1$, $B_2$, $B_3$, and $B_6$ may also be lost due to leaching into sugar solutions during the pre-treatment process. Additionally, it is possible that the high drying temperature after osmosis and UWB pre-treatment may contribute to the loss of these vitamins [52]. The low thermolability of these vitamins caused a significant reduction in their concentration during the drying process, which was accelerated with increasing drying temperatures from 50 to 70 °C. The results also reflect that the B vitamins concentration was decreased at higher US treatment time. The use of ultrasound might increase the availability of vitamins $B_1$, $B_2$, $B_3$, and $B_6$ in their free form by releasing the vitamin from its protein, membrane, or apoenzyme-bound state [78].

## 3.5. Antioxidant properties

### 3.5.1. Total phenolic content (TPC)

The antioxidant properties of fruits are mostly linked to their phenolic compounds [66]. From Fig. 4, the amount of TPC in the fresh *Taikor* samples was 18.45±0.12 mg/100 g, and after drying, the highest loss of TPC was found in 30 min glucose pretreated samples (7.94±0.55 mg/100 g) when dried at 70 °C. Compared to other samples, fructose-pretreated samples showed better TPC retention when dried at low temperatures. The TPC values decreased substantially with the increasing temperature. In previous research, Vega-Gálvez et al. [90] observed that the TPC in dried apples reduced as the drying temperature increased. The TPC loss at higher temperatures could be attributed to several causes. For instance, drying temperatures, various drying techniques, and earlier pretreatments all have a negative impact on TPC stability in food [37]. The significant TPC loss that was observed could be attributed to the *Taikor* samples' degraded cell walls, which accelerate a greater transfer of vacuolar liquid to the osmotic solution [93]. Additionally, a lack of oxygen during the osmotic pretreatment procedure may cause the lowest TPC in the sample pretreated with glucose [64].

**Table 4**
Vitamin $B_1$, $B_2$, $B_3$ & $B_6$ contents of fresh and dried Garcinia pedunculata slices at 50, 60, and 70 °C.

| Drying temperature | Sample | Vitamin $B_1$ (mg/g) | Vitamin $B_2$ (mg/g) | Vitamin $B_3$ (mg/g) | Vitamin $B_6$ (mg/g) |
|---|---|---|---|---|---|
| | **Fresh** | 3.75 ± 0.45$^{a}$ | 2.10 ± 0.11$^{a}$ | 1.42 ± 0.19$^{a}$ | 1.01 ± 0.11$^{a}$ |
| | S10 | 1.66 ± 0.23$^{d}$ | 1.15 ± 0.20$^{d}$ | 0.83 ± 0.12$^{c}$ | 0.42 ± 0.13$^{b}$ |
| | F10 | 2.73 ± 0.22$^{b}$ | 1.83 ± 0.16$^{b}$ | 1.17 ± 0.32$^{a}$ | 0.85 ± 0.34$^{abc}$ |
| | W10 | 2.25 ± 0.23$^{c}$ | 1.33 ± 0.34$^{c}$ | 1.06 ± 0.23$^{b}$ | 0.57 ± 0.17$^{c}$ |
| **50 °C** | G10 | 2.51 ± 0.27$^{b}$ | 1.65 ± 0.17$^{b}$ | 1.18 ± 0.26$^{ab}$ | 0.65 ± 0.15$^{c}$ |
| | S20 | 1.1 ± 0.35$^{f}$ | 1.15 ± 0.38$^{d}$ | 0.67 ± 0.31 $^{cd}$ | 0.49 ± 0.23$^{bc}$ |
| | F20 | 2.21 ± 0.23$^{c}$ | 1.25 ± 0.23$^{c}$ | 1.01 ± 0.19$^{b}$ | 0.67 ± 0.21$^{c}$ |
| | W20 | 1.82 ± 0.11$^{d}$ | 1.01 ± 0.17$^{d}$ | 0.77 ± 0.13$^{d}$ | 0.43 ± 0.16$^{c}$ |
| | G20 | 2.07 ± 0.13$^{c}$ | 1.27 ± 0.23$^{c}$ | 0.96 ± 0.19$^{bc}$ | 0.57 ± 0.24 $^{cd}$ |
| | S30 | 0.92 ± 0.11 $^{g}$ | 0.75 ± 0.12$^{da}$ | 0.49 ± 0.13$^{de}$ | 0.29 ± 0.11$^{f}$ |
| | F30 | 1.80 ± 0.22$^{d}$ | 1.07 ± 0.11$^{d}$ | 0.83 ± 0.31 $^{cd}$ | 0.67 ± 0.24$^{c}$ |
| | W30 | 1.33 ± 0.43$^{e}$ | 0.93 ± 0.14$^{d}$ | 0.57 ± 0.12$^{ef}$ | 0.32 ± 0.12$^{e}$ |
| | G30 | 1.47 ± 0.36$^{e}$ | 0.95 ± 0.21$^{d}$ | 0.64 ± 0.22 $^{cd}$ | 0.48 ± 0.10$^{d}$ |
| | S10 | 1.44 ± 0.31$^{e}$ | 1.03 ± 0.12$^{d}$ | 0.76 ± 0.37$^{d}$ | 0.38 ± 0.13$^{e}$ |
| | F10 | 2.55 ± 0.26$^{b}$ | 1.79 ± 0.09$^{b}$ | 1.03 ± 0.30$^{b}$ | 0.78 ± 0.12$^{b}$ |
| **60 °C** | W10 | 1.91 ± 0.23 $^{cd}$ | 1.34 ± 0.24$^{c}$ | 0.98 ± 0.22$^{c}$ | 0.55 ± 0.17$^{d}$ |
| | G10 | 2.54 ± 0.24$^{b}$ | 1.39 ± 0.18$^{c}$ | 0.95 ± 0.19$^{c}$ | 0.66 ± 0.23 $^{cd}$ |
| | S20 | 0.92 ± 0.15$^{a}$ | 1.03 ± 0.48$^{d}$ | 0.67 ± 0.36$^{d}$ | 0.38 ± 0.13$^{de}$ |
| | F20 | 1.95 ± 0.23 $^{cd}$ | 1.55 ± 0.37$^{bc}$ | 1.08 ± 0.17$^{b}$ | 0.57 ± 0.12$^{d}$ |
| | W20 | 1.83 ± 0.11$^{d}$ | 1.18 ± 0.13$^{d}$ | 0.78 ± 0.18$^{d}$ | 0.25 ± 0.07$^{f}$ |
| | G20 | 1.97 ± 0.13 $^{cd}$ | 1.34 ± 0.11$^{b}$ | 0.89 ± 0.23 $^{cd}$ | 0.43 ± 0.12$^{de}$ |
| | S30 | 0.88 ± 0.17 $^{g}$ | 0.65 ± 0.22$^{e}$ | 0.56 ± 0.14$^{de}$ | 0.28 ± 0.06$^{f}$ |
| | F30 | 1.85 ± 0.21$^{d}$ | 1.13 ± 0.11$^{d}$ | 0.93 ± 0.43$^{bcd}$ | 0.54 ± 0.04$^{d}$ |
| | W30 | 1.12 ± 0.33$^{ef}$ | 0.69 ± 0.24$^{e}$ | 0.66 ± 0.24 $^{cd}$ | 0.29 ± 0.02$^{f}$ |
| | G30 | 1.21 ± 0.24$^{ef}$ | 1.08 ± 0.17$^{d}$ | 0.76 ± 0.25 $^{cd}$ | 0.34 ± 0.08$^{e}$ |
| | S10 | 1.25 ± 0.17$^{a}$ | 1.08 ± 0.22$^{d}$ | 0.77 ± 0.37 $^{cd}$ | 0.43 ± 0.13$^{b}$ |
| **70 °C** | F10 | 2.13 ± 0.25$^{c}$ | 1.61 ± 0.43$^{b}$ | 1.02 ± 0.23$^{b}$ | 0.69 ± 0.24$^{bcd}$ |
| | W10 | 1.89 ± 0.23$^{d}$ | 1.23 ± 0.34 $^{cd}$ | 0.97 ± 0.20$^{c}$ | 0.45 ± 0.15$^{de}$ |
| | G10 | 2.01 ± 0.33$^{a}$ | 1.88 ± 0.25$^{b}$ | 1.06 ± 0.33$^{b}$ | 0.73 ± 0.14$^{bc}$ |
| | S20 | 1.07 ± 0.38e$^{fg}$ | 1.05 ± 0.23$^{d}$ | 0.59 ± 0.36$^{cde}$ | 0.36 ± 0.03$^{e}$ |
| | F20 | 2.03 ± 0.21$^{c}$ | 1.34 ± 0.36 $^{cd}$ | 0.92 ± 0.19$^{c}$ | 0.62 ± 0.20 $^{cd}$ |
| | W20 | 1.41 ± 0.15$^{e}$ | 0.97 ± 0.13$^{d}$ | 0.47 ± 0.11$^{e}$ | 0.33 ± 0.10$^{e}$ |
| | G20 | 2.01 ± 0.23$^{c}$ | 1.63 ± 0.48$^{bc}$ | 0.93 ± 0.23$^{c}$ | 0.42 ± 0.14$^{d}$ |
| | S30 | 0.72 ± 0.22 $^{g}$ | 0.68 ± 0.17$^{ef}$ | 0.39 ± 0.11$^{f}$ | 0.21 ± 0.09$^{ef}$ |
| | F30 | 1.92 ± 0.21 $^{cd}$ | 0.87 ± 0.23$^{e}$ | 0.66 ± 0.25$^{def}$ | 0.45 ± 0.12$^{de}$ |

(*continued on next page*)

**Table 4** (*continued*)

| Drying temperature | Sample | Vitamin $B_1$ (mg/g) | Vitamin $B_2$ (mg/g) | Vitamin $B_3$ (mg/g) | Vitamin $B_6$ (mg/g) |
|---|---|---|---|---|---|
| | W30 | 1.31 ± 0.41$^{e}$ | 0.65 ± 0.27$^{ef}$ | 0.48 ± 0.17$^{ef}$ | 0.22 ± 0.07$^{ef}$ |
| | G30 | 1.92 ± 0.27 $^{cd}$ | 0.47 ± 0.18$^{f}$ | 0.49 ± 0.12$^{ef}$ | 0.22 ± 0.05$^{f}$ |

* The values with the different superscripts in the same column are significantly different from each other.

Moreover, the decrease in TPC concentration may have resulted from ultrasonic cavitation, which hastened the movement of certain minor constituents in the food, mainly soluble nutrients from the sample, and created microspores (channels) during the pretreatments, as stated by Ren et al. [73]. Multiple studies suggested that the use of ultrasound in osmotic dehydration led to an increase in the transfer of phenolic compounds from the fruit tissue to the osmotic solution [73,83]. This movement might be associated with the lower phenolic content of the fruits samples with longer US treatment. According to research, the drying procedure affects the phenolic compounds and their antioxidant effects in some murtilla fruits [75,10]. Almeida et al. [7] also claimed that osmotic dehydration preserves the bioactive chemicals of fruits.

### 3.5.2. Total flavonoid content (TFC)

Heat-sensitive substances known as flavonoids have antioxidant properties. Fresh *Taikor* sample showed the maximum TFC value (17.77 ±0.28 mg/100 g), which was decreased after pretreatment and as the temperature increased from 50 to 70 °C (Fig. 5). Fructose and sucrose pretreated samples showed better retention of phenolic substances.

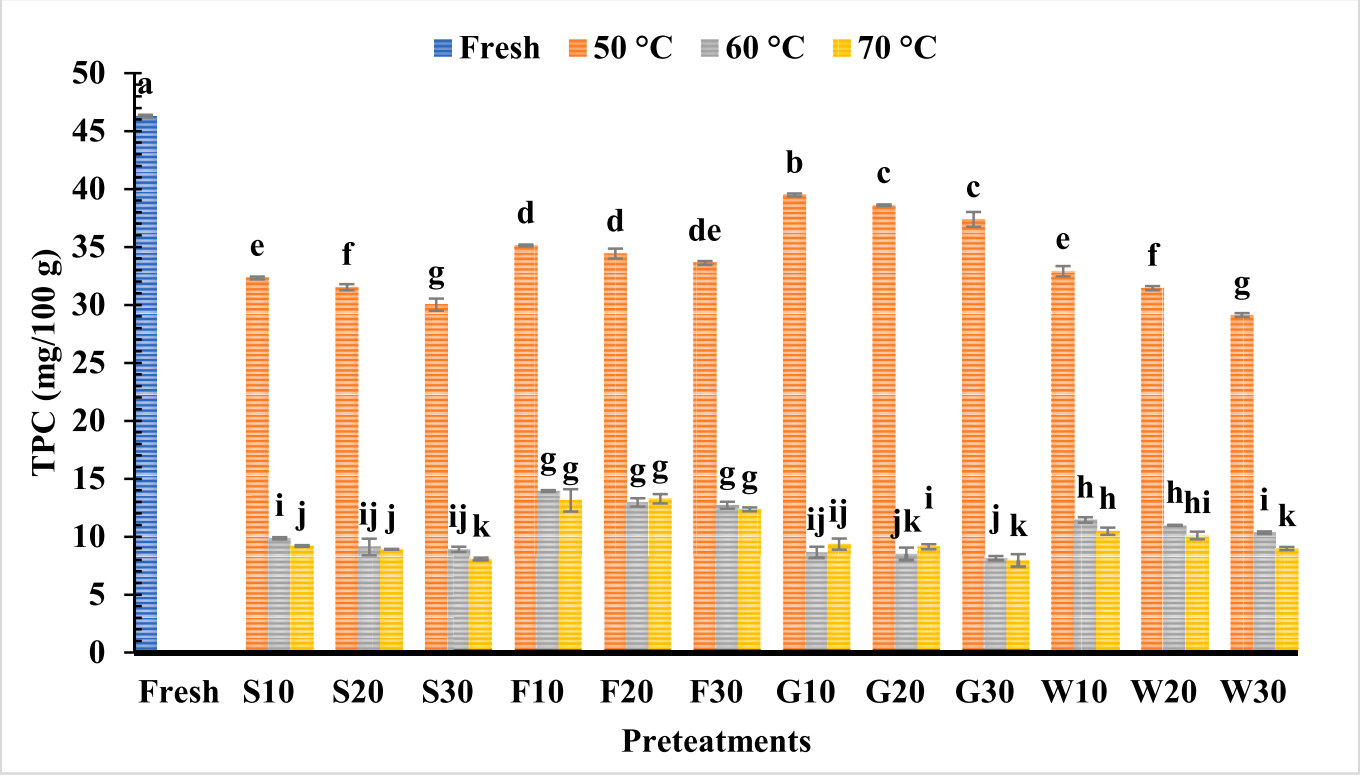


**Fig. 4.** TPC of pretreated *Taikor* samples dried at 50, 60, and 70 °C.

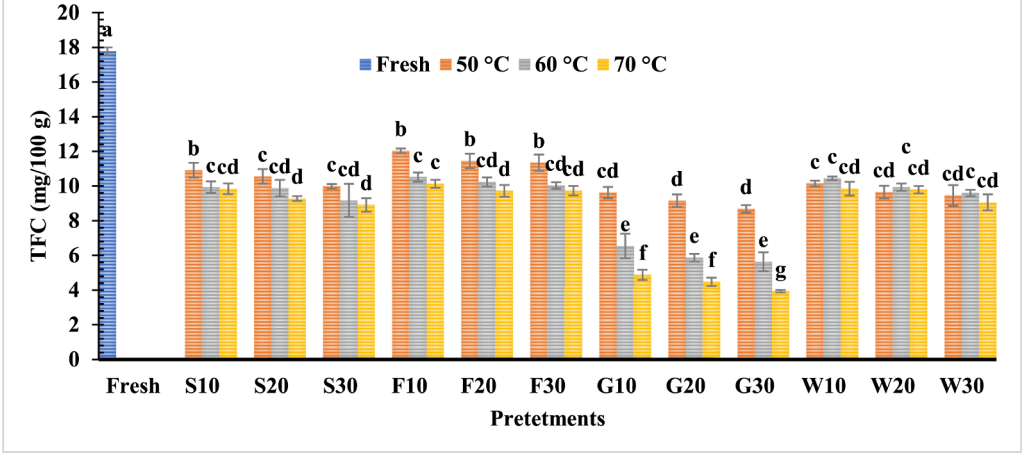


**Fig. 5.** Total flavonoid content of *Taikor* samples at different temperatures.

Glucose pretreated *Garcinia pedunculata* dried at 70 °C exhibited the most significant loss (3.94±0.06 mg/100 g), while fructose treated sample dried at 50 °C showed the minimum loss (12.03±0.05 mg/100 g). The reduction in total flavonoids at higher temperatures may be due to the breakdown of flavonoids at high heat. The breakdown of cell walls caused by increased temperature results in the release of hydrolytic and oxidative enzymes, which can damage the antioxidant activity of food [21]. During heat treatment, the structural transformation of flavonoid molecules may also affect the total antioxidant activity of dried products [41,38].

However, the TFC did not vary much among the treatment duration, meaning that the phenolic compounds were not readily soluble in water. In a study by Abbaspour-Gilandeh et al. [2], it was found that ultrasonic waves cause the release, modification, and denaturation of particular enzymes that act on polyphenolics. They found that by subjecting hawthorn fruit to ultrasonic pretreatment before drying, the amount of TFC present was significantly increased in comparison to using hot air drying alone.

### 3.5.3. DPPH radical scavenging activity

Phenolic compounds exhibit distinct properties depending on osmotic solution concentration, ultrasound, oxygen, temperature, and other variables. They also have a considerable antioxidant ability. The increases in the antioxidant activity of the pretreated samples exhibited variations similar to those in the TPC. Reduction in water content and increase in soluble solids are often connected with the leaching out of water-soluble, and low molecular components in sample extract, which include chemicals contributing to the antioxidant activities [59,48]. The DPPH free radical scavenging activity was employed to assess the antioxidant activity. The ability of various antioxidative substances to donate electrons can be quickly assessed using the DPPH radical scavenging activity assay [76].

According to Fig. 6, in comparison to the fresh sample, the free radical scavenging activity of dried samples was considerably lower. The highest $EC_{50}$ value (67 ± 0.06 g/100 g) was observed in fresh *Taikor* sample. The minimum $EC_{50}$ value (16.40 ± 0.23 g/100 g) was found in the glucose-treated sample dried at 70 °C. Fig. 6 represents that the DPPH radical scavenging activity retained better at low drying temperatures. The reduced DPPH antioxidant activity determined by osmotic pretreatment in US bath is in agreement with the findings stated by Romero and Yépez [81]. They found that sonicating Andean blackberries in distilled water for 30 min at a frequency of 24 kHz reduced their antioxidant activity. This decline was attributed to the fruit's antioxidative compounds migrating into the liquid medium and to changes in the fruit peel that promote the transfer mechanism of its components to the liquid by decreasing resistance (Pirce et al., 2021b). Adiletta et al. [4] and İzli [42] found similar results for grapes and dates, respectively.

However, the antioxidant activity of the *Taikor* slices was shown to be better retained after the dipping pretreatments. In earlier research, Hossain et al. [40] and Zzaman et al. [93] observed a comparable impact of high temperature drying on the antioxidant activity of dried pineapple and *Gracinia pendaculata*, respectively, that had undergone osmotic pretreatment and showed similar characteristics.

### 3.6. Microbial load

The microbial load in the dried product defines the standard sanitation level. Fruits are dehydrated to enhance the shelf life. Table 5 shows the microbial load in fresh *Taikor* samples under various treatment settings and after drying. Fresh *Taikor* samples had bacterial and fungal counts of 5.50±0.06 and 6.66±0.10 log (CFU/g), respectively. In certain situations, the microbial load steadily dropped as the drying temperature increased. The bacterial cell's ability to survive was affected by the pretreatment solutions as well. During pretreatment with the osmotic solution, dehydration of bacteria cells is possible, which can cause protein denaturation, RNA and DNA breakage, cell wall destruction, and modification of cytoplasmic membrane [15].

From Table 5, the maximum value (5.69±0.14 log CFU/g) of the bacterial count was found in W10 sample, and the highest value (6.57 ±0.4 log CFU/g) of the fungal count was also seen in W10 treated sample when dried at 50 °C. Almost all dried samples showed a

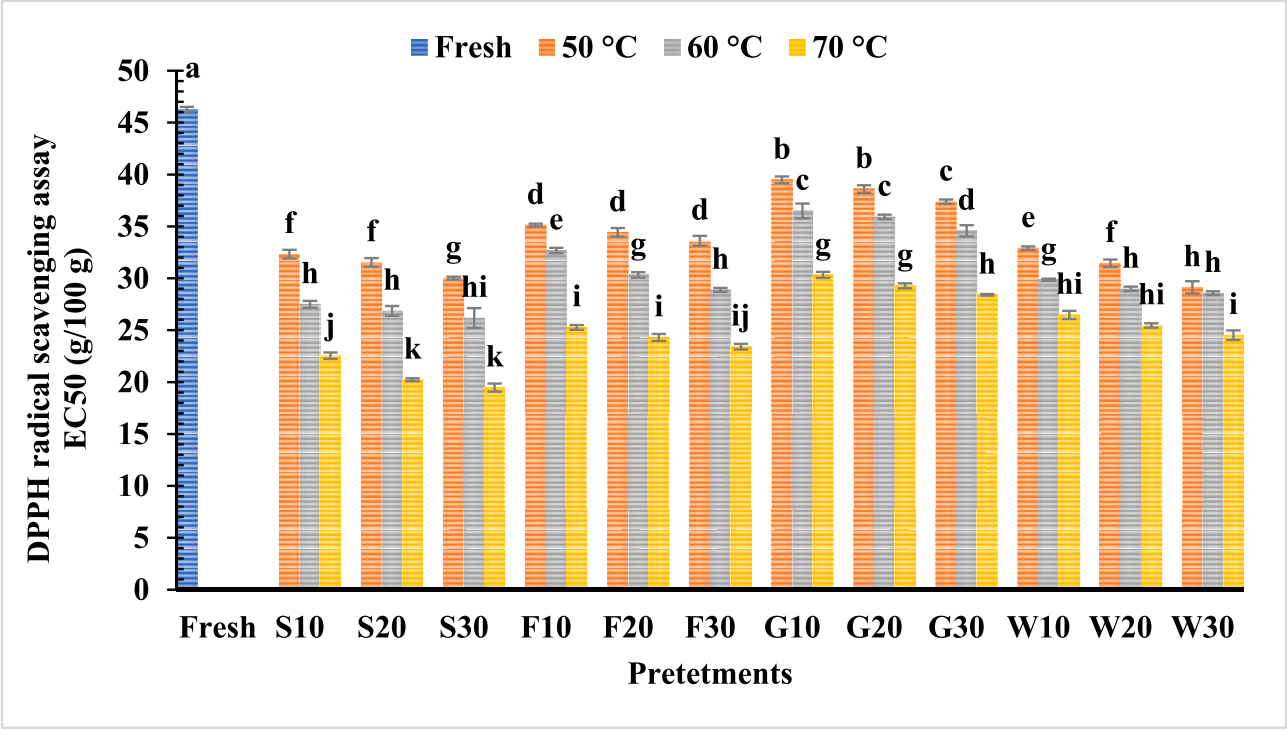


**Fig. 6.** DPPH radical scavenging activity of *Taikor* samples dried at different temperatures.

**Table 5**
Microbial load of fresh and dried Garcinia pedunculata slices with different pretreatments and drying temperatures.

| Drying temperature | Sample | Bacterial Count log (CFU/g) | Fungal Count log (CFU/g) |
|---|---|---|---|
| **50 °C** | **Fresh** | $5.50 \pm 0.06^{a}$ | $6.66 \pm 0.10^{a}$ |
| | **S10** | $4.43 \pm 0.20^{b}$ | $6.19 \pm 0.18^{a}$ |
| | **F10** | $4.38 \pm 0.1^{b}$ | $5.98 \pm 0.15^{a}$ |
| | **W10** | $5.69 \pm 0.14^{a}$ | $6.57 \pm 0.4^{a}$ |
| | **G10** | $4.32 \pm 0.62^{b}$ | $5.73 \pm 0.07^{b}$ |
| | **S20** | $4.31 \pm 0.23^{b}$ | $6.08 \pm 0.33^{g}$ |
| | **F20** | $4.36 \pm 0.52^{b}$ | $5.86 \pm 0.28^{b}$ |
| | **W20** | $5.61 \pm 0.23^{a}$ | $6.48 \pm 0.1^{i}$ |
| | **G20** | $4.31 \pm 0.13^{b}$ | $5.71 \pm 0.6^{b}$ |
| | **S30** | $4.07 \pm 0.16^{bc}$ | $5.99 \pm 0.37^{a}$ |
| | **F30** | $4.27 \pm 0.24^{b}$ | $5.89 \pm 0.70^{ab}$ |
| | **W30** | $5.60 \pm 0.37^{a}$ | $6.35 \pm 1.30^{a}$ |
| | **G30** | $4.29 \pm 0.02^{b}$ | $5.63 \pm 1.18^{abc}$ |
| | **S10** | $3.94 \pm 0.32^{bc}$ | $4.98 \pm 0.21^{c}$ |
| | **F10** | $3.87 \pm 0.41^{bc}$ | $4.40 \pm 0.35^{a}$ |
| | **W10** | $4.58 \pm 0.18^{b}$ | $5.17 \pm 0.3^{c}$ |
| | **G10** | $3.71 \pm 0.51^{cd}$ | $4.27 \pm 1.21^{de}$ |
| | **S20** | $3.92 \pm 0.56^{bc}$ | $4.97 \pm 1.43^{c}$ |
| **60 °C** | **F20** | $3.80 \pm 0.31^{c}$ | $4.34 \pm 0.48^{f}$ |
| | **W20** | $4.55 \pm 0.02^{b}$ | $5.15 \pm 1.03^{c}$ |
| | **G20** | $3.69 \pm 0.03^{d}$ | $4.23 \pm 1.36^{k}$ |
| | **S30** | $3.90 \pm 0.16^{bc}$ | $4.97 \pm 0.7^{c}$ |
| | **F30** | $3.80 \pm 0.14^{c}$ | $4.30 \pm 1.37^{l}$ |
| | **W30** | $4.50 \pm 0.7^{b}$ | $5.14 \pm 0.47^{c}$ |
| | **G30** | $3.65 \pm 0.14^{cd}$ | $4.20 \pm 1.56^{de}$ |
| **70 °C** | **S10** | $3.07 \pm 0.52^{d}$ | $3.40 \pm 0.13^{e}$ |
| | **F10** | $3.39 \pm 0.3^{d}$ | $3.19 \pm 1.55^{def}$ |
| | **W10** | $3.97 \pm 0.8^{bc}$ | $4.08 \pm 1.6^{ef}$ |
| | **G10** | $3.32 \pm 0.27^{d}$ | $3.07 \pm 1.39^{ef}$ |
| | **S20** | $3.01 \pm 0.6^{b}$ | $3.38 \pm 1.02^{ef}$ |
| | **F20** | $3.37 \pm 0.10^{d}$ | $3.19 \pm 0.9^{fg}$ |
| | **W20** | $3.96 \pm 0.3^{bc}$ | $4.06 \pm 1.22^{def}$ |
| | **G20** | $3.31 \pm 0.8^{d}$ | $3.04 \pm 0.6^{efg}$ |
| | **S30** | $3.00 \pm 0.34^{e}$ | $3.33 \pm 1.3^{defg}$ |
| | **F30** | $3.36 \pm 0.9^{d}$ | $3.14 \pm 1.21^{efg}$ |
| | **W30** | $3.95 \pm 0.01^{bc}$ | $4.00 \pm 1.7^{def}$ |
| | **G30** | $3.30 \pm 0.38^{d}$ | $2.99 \pm 1.0^{efg}$ |

* The values with the different superscripts in the same column are significantly different from each other.

significant impact of drying temperatures on the fungal load count. At 70 °C drying temperature, the water-treated sample exhibited the lowest microbial load, which was of 3.00±0.34log CFU/g. The lowest fungal count (2.99±1.0 log CFU/g) was found for G30 sample dried at 70 °C.

The increased drying temperature helped to reduce the fungal load in the dried *Taikor* sample. It is worth noting that ultrasonic waves generate microbubble cavitation, which could be responsible for the reduction of microbial count in pretreated samples [91]. According to prior research, oxidative stress and free radicals were formed because of the influence of ultrasound. This triggered an increase in damaged cell walls and denatured enzyme activity in microorganisms, which resulted in a slowdown in the growth of bacteria [88].

The Indian microbiological standards for dried plant products stipulate that the aerobic plate count of dried fruits should be below 5 log CFU/g, with a desirable level of 4 log CFU/g. Additionally, the Food Safety and Standards Authority of India determined that dried fruit's acceptable fungal load is 4 log CFU/g, and the satisfactory load is below 2 log CFU/g [76]. According to Ireland's point-of-sale microbiological quality criteria, dried fruit with a CFU/g level of less than 5 log is acceptable [87]. The findings of the current investigation show that, with some exceptions, most dried *Taikor* slices were within the safety limit of the previously mentioned microbiological safety standards.

## 4. Conclusion

In this study, the influence of osmotic and ultrasonic water bath pretreatments on the drying characteristics and some quality parameters of *Gracinia pendaculata*, such as color, β-carotene (vitamin A), vitamin $B_1$, $B_2$, $B_3$, and $B_6$, vitamin C, TFC, TPC, antioxidant activity, and total microbial count were investigated in fresh and treated dried *Taikor* slices. The final products' quality was significantly affected by both the temperature of the samples and the pretreatment they underwent. This study found that by drying at a lower temperature with a glucose solution, the chemical properties were preserved to the greatest extent possible. The color parameters were better preserved by fructose pretreatment. Longer sonication time reduced the microbial and fungal load, though it was associated with a relatively higher loss of nutritional compounds. However, drying at a low temperature took a longer time to complete the drying process. Future research on Garcinia pedunculata, and other underutilized fruits and vegetables may benefit from this study's findings about preserving these foods while preserving as much of their nutritious qualities as possible.

## CRediT authorship contribution statement

**Mohammad Afzal Hossain:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – review & editing. **Sudipta Talukder:** Methodology, Writing – original draft. **Aftab Uz Zaman:** Methodology, Data curation, Writing – original draft. **Animesh Sarkar:** Resources, Software. **Md. Yasin:** Methodology, Data curation. **Rahul Biswas:** Data curation, Software, Methodology.

## 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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## References

[1] R.M. Aadil, X.A. Zeng, Z. Han, D.W. Sun, Effects of ultrasound treatments on quality of grapefruit juice, Food Chemistry 141 (3) (2013) 3201–3206, https://doi.org/10.1016/j.foodchem.2013.06.008.
[2] Y. Abbaspour-Gilandeh, M. Kaveh, H. Fatemi, M. Aziz, Combined hot air, microwave, and infrared drying of hawthorn fruit: Effects of ultrasonic pretreatment on drying time, energy, qualitative, and bioactive compounds' properties, Foods 10 (5) (2021), https://doi.org/10.3390/FOODS10051006.
[3] Adiletta, G., Russo, P., Crescitelli, A., & di Matteo, M. (2016). Combined Pretreatment for Enhancing Quality of Dried and Rehydrated Eggplant. *Food and Bioprocess Technology 2016 9:11*, *9*(11), 1912–1923. https://doi.org/10.1007/S11947-016-1778-Y.
[4] G. Adiletta, P. Russo, W. Senadeera, M. di Matteo, Drying characteristics and quality of grape under physical pretreatment, Journal of Food Engineering 172 (2016) 9–18, https://doi.org/10.1016/J.JFOODENG.2015.06.031.
[5] S. Ahmed, A. Jubair, M.A. Hossain, M.M. Hossain, M.S. Azam, M. Biswas, Free radical-scavenging capacity and HPLC-DAD screening of phenolic compounds from pulp and seed of *Syzygium claviflorum* fruit, Journal of Agriculture and Food Research 6 (2021) 100203, https://doi.org/10.1016/J.JAFR.2021.100203.
[6] T. Aktas, S. Fujii, Y. Kawano, S. Yamamoto, Effects of Pretreatments of Sliced Vegetables with Trehalose on Drying Characteristics and Quality of Dried Products, Food and Bioproducts Processing 85 (3) (2007) 178–183, https://doi.org/10.1205/FBP07037.
[7] J.A.R. Almeida, L.P. Mussi, D.B. Oliveira, N.R. Pereira, Effect of Temperature and Sucrose Concentration on the Retention of Polyphenol Compounds and Antioxidant Activity of Osmotically Dehydrated Bananas, Journal of Food Processing and Preservation 39 (6) (2015) 1061–1069, https://doi.org/10.1111/JFPP.12321.
[8] E. Amami, W. Khezami, S. Mezrigui, L.S. Badwaik, A.K. Bejar, C.T. Perez, N. Kechaou, Effect of ultrasound-assisted osmotic dehydration pretreatment on the convective drying of strawberry, Ultrasonics Sonochemistry 36 (2017) 286–300, https://doi.org/10.1016/j.ultsonch.2016.12.007.
[9] F.R. Assis, R.M.S.C. Morais, A.M.M.B. Morais, Mass Transfer in Osmotic Dehydration of Food Products: Comparison Between Mathematical Models, Food

Engineering Reviews 8 (2) (2016) 116–133, https://doi.org/10.1007/S12393-015-9123-1/METRICS.
[10] T.R. Augusto, E.S. Scheuermann Salinas, S.M. Alencar, M.A.B.R. D'Arce, A.C. de Camargo, T.M.F. de Vieira, S., Phenolic compounds and antioxidant activity of hydroalcoholic extracts of wild and cultivated murtilla (Ugni molinae turcz.), Food Science and Technology (brazil) 34 (4) (2015) 667–673, https://doi.org/10.1590/1678-457X.6393.
[11] M. Bantle, K. Kolsaker, T.M. Eikevik, Modification of the Weibull distribution for modeling atmospheric freeze-drying of food, Drying Technology 29 (10) (2011) 1161–1169, https://doi.org/10.1080/07373937.2011.574242.
[12] A.P. Bartolome, P. Ruperez, C. Fuster, Freezing Rate and Frozen Storage Effects on Color and Sensory Characteristics of Pineapple Fruit Slices, Journal of Food Science 61 (1) (1996) 154–156, https://doi.org/10.1111/J.1365-2621.1996.TB14747.X.
[13] M.d. Belal, M.A. Hossain, S. Mitra, W. Zzaman, Effect of foaming agent concentration and foam stabilizer on the foaming capacity and physical properties of tomato powder dried at different temperature, Journal of Microbiology, Biotechnology and Food Sciences (2022) e4741–e. https://doi.org/10.55251/JMBFS.4741.
[14] R. Biswas, M.A. Hossain, W. Zzaman, Thin layer modeling of drying kinetics, rehydration kinetics and color changes of osmotic pre-treated pineapple (Ananas comosus) slices during drying: Development of a mechanistic model for mass transfer, Innovative Food Science & Emerging Technologies 80 (2022) 103094, https://doi.org/10.1016/J.IFSET.2022.103094.
[15] S. Bourdoux, D. Li, A. Rajkovic, F. Devlieghere, M. Uyttendaele, Performance of Drying Technologies to Ensure Microbial Safety of Dried Fruits and Vegetables, Comprehensive Reviews in Food Science and Food Safety 15 (6) (2016) 1056–1066, https://doi.org/10.1111/1541-4337.12224.
[16] A. Brasiello, G. Iannone, G. Adiletta, S. de Pasquale, P. Russo, M. di Matteo, Mathematical model for dehydration and shrinkage: Prediction of eggplant's MRI spatial profiles, Journal of Food Engineering 203 (2017) 1–5, https://doi.org/10.1016/j.jfoodeng.2017.01.013.
[17] D.M. Bruce, Exposed-layer barley drying: three models fitted to new data up to 150 C, Journal of Agricultural Engineering Research 32 (4) (1985) 337–348, https://doi.org/10.1016/0021-8634(85)90098-8.
[18] A. Chandra, S. Kumar, A. Tarafdar, P.K. Nema, Ultrasonic and osmotic pretreatments followed by convective and vacuum drying of papaya slices, Journal of the Science of Food and Agriculture 101 (6) (2021) 2264–2272, https://doi.org/10.1002/jsfa.10847.
[19] J.L.G. Corrêa, M.C. Rasia, A. Mulet, J.A. Cárcel, Influence of ultrasound application on both the osmotic pretreatment and subsequent convective drying of pineapple (Ananas comosus), Innovative Food Science & Emerging Technologies 41 (2017) 284–291, https://doi.org/10.1016/J.IFSET.2017.04.002.
[20] A.S. da Costa Ribeiro, E. Aguiar-Oliveira, R.R. Maldonado, Optimization of osmotic dehydration of pear followed by conventional drying and their sensory quality, LWT - Food Science and Technology 72 (2016) 407–415, https://doi.org/10.1016/J.LWT.2016.04.062.
[21] V. Dewanto, W. Xianzhong, K.K. Adom, R.H. Liu, Thermal Processing Enhances the Nutritional Value of Tomatoes by Increasing Total Antioxidant Activity, Journal of Agricultural and Food Chemistry 50 (10) (2002) 3010–3014, https://doi.org/10.1021/JF0115589.
[22] A.O. Dissa, H. Desmorieux, J. Bathiebo, J. Koulidiati, Convective drying characteristics of Amelie mango (Mangifera indica L. cv. 'Amelie') with correction for shrinkage, Journal of Food Engineering 88 (4) (2008) 429–437, https://doi.org/10.1016/J.JFOODENG.2008.03.008.
[23] I. Doymaz, Influence of pretreatment solution on the drying of sour cherry, Journal of Food Engineering 78 (2) (2007) 591–596, https://doi.org/10.1016/J.JFOODENG.2005.10.037.
[24] I. Doymaz, Air-drying characteristics of tomatoes, Journal of Food Engineering 78 (4) (2007) 1291–1297, https://doi.org/10.1016/J.JFOODENG.2005.12.047.
[25] V. Dueik, P. Robert, P. Bouchon, Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps, Food Chemistry 119 (3) (2010) 1143–1149, https://doi.org/10.1016/j.foodchem.2009.08.027.
[26] A. Fernandes, M.J. Pacheco, L. Ciríaco, A. Lopes, Review on the electrochemical processes for the treatment of sanitary landfill leachates: Present and future, Applied Catalysis b: Environmental 176–177 (2015) 183–200, https://doi.org/10.1016/J.APCATB.2015.03.052.
[27] F.A.N. Fernandes, S. Rodrigues, J.A. Cárcel, J.V. García-Pérez, Ultrasound-Assisted Air-Drying of Apple (Malus domestica L.) and Its Effects on the Vitamin of the Dried Product, Food and Bioprocess Technology 8 (7) (2015) 1503–1511, https://doi.org/10.1007/s11947-015-1519-7.
[28] F.A.N. Fernandes, S. Rodrigues, J.A. Cárcel, J.V. Garcia-Pérez, Effects of ultrasound-assisted air drying on vitamins and carotenoids of cherry tomatoes, Drying Technology 34 (8) (2016) 986–996, https://doi.org/10.1080/07373937.2015.1090445.
[29] J. Garcia-Noguera, F.I. Oliveira, M.I. Gallão, C.L. Weller, S. Rodrigues, F. A. Fernandes, Ultrasound-assisted osmotic dehydration of strawberries: effect of pretreatment time and ultrasonic frequency, Drying Technology 28 (2) (2010) 294–303, https://doi.org/10.1080/07373930903530402.
[30] J. Garcia-Noguera, F.I.P. Oliveira, C.L. Weller, S. Rodrigues, F.A.N. Fernandes, Effect of ultrasonic and osmotic dehydration pre-treatments on the colour of freeze dried strawberries, Journal of Food Science and Technology 51 (9) (2014) 2222–2227, https://doi.org/10.1007/s13197-012-0724-x.
[31] R.K. Goyal, A.R.P. Kingsly, M.R. Manikantan, S.M. Ilyas, Thin-layer Drying Kinetics of Raw Mango Slices, Biosystems Engineering 95 (1) (2006) 43–49, https://doi.org/10.1016/J.BIOSYSTEMSENG.2006.05.001.
[32] R.P.F. Guiné, The Drying of Foods and Its Effect on the Physical-Chemical, Sensorial and Nutritional Properties, ETP International Journal of Food Engineering (2018) 93–100. https://doi.org/10.18178/ijfe.4.2.93-100.
[33] S.M.B. Hashemi, D. Jafarpour, Antimicrobial and antioxidant properties of Saturn peach subjected to ultrasound-assisted osmotic dehydration, Journal of Food Measurement and Characterization 15 (2021) 2516–2523, https://doi.org/10.1007/s11694-021-00842-9.
[34] S.M. Henderson, Grain drying theory, I. Temperature effect on drying coefficient, Journal of Agricultural Engineering Research 6 (3) (1961) 169–173.
[35] M.A.R. Himel, T. Ahmed, M.A. Hossain, M.S. Moazzem, Response surface optimization to extract antioxidants from freeze-dried seeds and peel of pomegranate (Punica granatum L.), Biomass Conversion and Biorefinery (2022) 1–16, https://doi.org/10.1007/S13399-022-03074-Z/METRICS.
[36] B. Hiranvarachat, S. Devahastin, N. Chiewchan, Effects of acid pretreatments on some physicochemical properties of carrot undergoing hot air drying, Food and Bioproducts Processing 89 (2) (2011) 116–127, https://doi.org/10.1016/J.FBP.2010.03.010.
[37] E. Horuz, H. Bozkurt, H. Karataş, M. Maskan, Effects of hybrid (microwave-convectional) and convectional drying on drying kinetics, total phenolics, antioxidant capacity, vitamin C, color and rehydration capacity of sour cherries, Food Chemistry 230 (2017) 295–305, https://doi.org/10.1016/j.foodchem.2017.03.046.
[38] M.A. Hossain, N.U. Ahmad, M. Alam, M.M. Hossain, A. Sarkar, Screening of different extraction methods for maximum production of total flavonoids, tannins, and antioxidants from *Centella asiatica*, Food Research 8 (1) (2024) 44–51. https://doi.org/10.26656/fr.2017.8(1).057.
[39] M.A. Hossain, M.Y. Arafat, M. Alam, M.M. Hossain, Effect of solvent types on the antioxidant activity and total flavonoids of some Bangladeshi legumes, Food Research 5 (4) (2021) 329–335. https://doi.org/10.26656/fr.2017.5(4).035.
[40] M.A. Hossain, P. Dey, R.I. Joy, Effect of osmotic pretreatment and drying temperature on drying kinetics, antioxidant activity, and overall quality of taikor (Garcinia pedunculata Roxb.) slices, Saudi Journal of Biological Sciences 28 (12) (2021) 7269–7280, https://doi.org/10.1016/j.sjbs.2021.08.038.
[41] M.A. Hossain, S. Mitra, M. Belal, W. Zzaman, Effect of foaming agent concentration and drying temperature on biochemical properties of foam mat dried tomato powder, Food Research 5 (2) (2021) 291–297. https://doi.org/10.26656/fr.2017.5(1).372.
[42] G. İzli, Total phenolics, antioxidant capacity, colour and drying characteristics of date fruit dried with different methods, Food Science and Technology 37 (1) (2016) 139–147, https://doi.org/10.1590/1678-457X.14516.
[43] N. Izli, G. Izli, O. Taskin, Influence of different drying techniques on drying parameters of mango, Food Science and Technology 37 (4) (2017) 604–612, https://doi.org/10.1590/1678-457X.28316.
[44] C. Kadakal, T. Duman, R. Ekinci, Thermal degradation kinetics of ascorbic acid, thiamine and riboflavin in rosehip (Rosa canina L) nectar, Food Science and Technology 38 (2017) 667–673, https://doi.org/10.1590/1678-457X.11417.
[45] E. Karacabey, S. Buzrul, Modeling and predicting the drying kinetics of apple and pear: Application of the Weibull model, Chemical Engineering Communications 204 (5) (2017) 573–579, https://doi.org/10.1080/00986445.2017.1291427.
[46] M. Kashaninejad, L.G. Tabil, B. Crerar, in: Drying Characteristics of Purslane (portulaca Oleraceae l.), American Society of Agricultural and Biological Engineers, 2003, p. (p. 1)..
[47] F. Kaymak-Ertekin, Drying and Rehydrating Kinetics of Green and Red Peppers, Journal of Food Science 67 (1) (2002) 168–175, https://doi.org/10.1111/J.1365-2621.2002.TB11378.X.
[48] M. Kebe, C.M.C.G. Renard, M. el Maâtaoui, G.N.G. Amani, J.F. Maingonnat, Leaching of polyphenols from apple parenchyma tissue as influenced by thermal treatments, Journal of Food Engineering 166 (2015) 237–246, https://doi.org/10.1016/J.JFOODENG.2015.05.037.
[49] H. Keran, M. Salkić, A. Odobašić, M. Jašić, N. Ahmetović, I. Šestan, The Importance of Determination of some Physical – Chemical Properties of Wheat and Flour, Agriculturae Conspectus Scientificus 74 (3) (2009) 197–200.
[50] D. Kohli, N.C. Shahi, A. Kumar, Drying kinetics and activation energy of Asparagus root (Asparagus racemosus Wild.) for different methods of drying. Current Research, Nutrition and Food Science 6 (1) (2018) 191–202. https://doi.org/10.12944/CRNFSJ.6.1.22.
[51] S.J. Kowalski, J. Szadzińska, J. Łechtańska, Non-stationary drying of carrot: Effect on product quality, Journal of Food Engineering 118 (4) (2013) 393–399, https://doi.org/10.1016/J.JFOODENG.2013.04.028.
[52] P. Krishnan, B. Ramakrishnan, K.R. Reddy, V.R. Reddy, High-Temperature Effects on Rice Growth, Yield, and Grain Quality, Advances in Agronomy 111 (2011) 87–206, https://doi.org/10.1016/B978-0-12-387689-8.00004-7.
[53] Kumari, V., Yadav, B. S., B. Yadav, R., & Nema, P. K. (2020). Effect of osmotic agents and ultasonication on osmo-convective drying of sweet lime (Citrus limetta) peel. Journal of Food Process Engineering, 43(4), e13371. https://doi.org/10.1111/JFPE.13371.
[54] J.S. Lee, L.S. Lim, Osmo-dehydration pretreatment for drying of pumpkin slice, International Food Research Journal 18 (4) (2011) 1223.
[55] R. Lemus-Mondaca, A. Vega-Gálvez, L. Zura-Bravo, A.H. Kong, *Stevia rebaudiana* Bertoni, source of a high-potency natural sweetener: A comprehensive review on the biochemical, nutritional and functional aspects, Food Chemistry 132 (3) (2012) 1121–1132, https://doi.org/10.1016/J.FOODCHEM.2011.11.140.
[56] S.U. Marzuki, Y. Pranoto, T. Khumsap, L.T. Nguyen, Effect of blanching pretreatment and microwave-vacuum drying on drying kinetics and physicochemical properties of purple-fleshed sweet potato, Journal of Food Science

and Technology 58 (8) (2021) 2884–2895, https://doi.org/10.1007/S13197-020-04789-5/METRICS.
[57] S. Methakhup, N. Chiewchan, S. Devahastin, Effects of drying methods and conditions on drying kinetics and quality of Indian gooseberry flake, LWT - Food Science and Technology 38 (6) (2005) 579–587, https://doi.org/10.1016/J.LWT.2004.08.012.
[58] D. Mierzwa, S.J. Kowalski, Ultrasound-assisted osmotic dehydration and convective drying of apples: Process kinetics and quality issues, Chemical and Process Engineering 37 (3) (2016), https://doi.org/10.1515/cpe-2016-0031.
[59] M. Mieszczakowska-Frąc, B. Dyki, D. Konopacka, Effects of Ultrasound on Polyphenol Retention in Apples After the Application of Predrying Treatments in Liquid Medium, Food and Bioprocess Technology 9 (3) (2016) 543–552, https://doi.org/10.1007/S11947-015-1648-Z/FIGURES/4.
[60] M. Muzolf-Panek, T. Kleiber, A. Kaczmarek, Effect of increasing manganese concentration in nutrient solution on the antioxidant activity, vitamin C, lycopene and polyphenol contents of tomato fruit, Food Additives and Contaminants - Part A Chemistry, Analysis, Control, Exposure and Risk Assessment 34 (3) (2017) 379–389, https://doi.org/10.1080/19440049.2016.1277037.
[61] P.S. Negi, G.K. Jayaprakasha, B.S. Jena, Antibacterial activity of the extracts from the fruit rinds of *Garcinia cowa* and *Garcinia pedunculata* against food borne pathogens and spoilage bacteria, LWT 41 (10) (2008) 1857–1861, https://doi.org/10.1016/j.lwt.2008.02.009.
[62] M. Nowacka, M. Dadan, U. Tylewicz, Current applications of ultrasound in fruit and vegetables osmotic dehydration processes, Applied Sciences 11 (3) (2021) 1269, https://doi.org/10.3390/app11031269.
[63] D.I. Onwude, N. Hashim, R.B. Janius, N.M. Nawi, K. Abdan, Modeling the Thin-Layer Drying of Fruits and Vegetables: A Review, Comprehensive Reviews in Food Science and Food Safety 15 (3) (2016) 599–618, https://doi.org/10.1111/1541-4337.12196.
[64] R. Osae, C. Zhou, B. Xu, W. Tchabo, H.E. Tahir, A.T. Mustapha, H. Ma, Effects of ultrasound, osmotic dehydration, and osmosonication pretreatments on bioactive compounds, chemical characterization, enzyme inactivation, color, and antioxidant activity of dried ginger slices, Journal of Food Biochemistry 43 (5) (2019), https://doi.org/10.1111/jfbc.12832.
[65] G.E. Page, Factors Influencing the Maximum Rates of Air Drying Shelled Corn in Thin layers, Purdue University, 1949.
[66] F. Pirce, T.M.F.S. Vieira, T.R. Augusto-Obara, S.M. Alencar, F. Romero, E. Scheuermann, Effects of convective drying assisted by ultrasound and osmotic solution on polyphenol, antioxidant and microstructure of murtilla (Ugni molinae Turcz) fruit, Journal of Food Science and Technology 58 (1) (2021) 138–146, https://doi.org/10.1007/s13197-020-04523-1.
[67] A. Rahaman, X.A. Zeng, A. Kumari, M. Rafiq, A. Siddeeg, M.F. Manzoor, Z. Baloch, Z. Ahmed, Influence of ultrasound-assisted osmotic dehydration on texture, bioactive compounds and metabolites analysis of plum, Ultrasonics Sonochemistry 58 (2019) 104643, https://doi.org/10.1016/J.ULTSONCH.2019.104643.
[68] M.M. Rahman, F.E. Khan, R. Das, M.A. Hossain, Antioxidant activity and total phenolic content of some indigenous fruits of Bangladesh, International Food Research Journal 23 (6) (2016) 2399–2404.
[69] A.L. Raoult-Wack, Recent advances in the osmotic dehydration of foods, Trends in Food Science & Technology 5 (8) (1994) 255–260, https://doi.org/10.1016/0924-2244(94)90018-3.
[70] L.A. Ramallo, R.H. Mascheroni, Quality evaluation of pineapple fruit during drying process, Food and Bioproducts Processing 90 (2) (2012) 275–283, https://doi.org/10.1016/J.FBP.2011.06.001.
[71] P. Rani, P.P. Tripathy, Drying characteristics, energetic and exergetic investigation during mixed-mode solar drying of pineapple slices at varied air mass flow rates, Renewable Energy 167 (2021) 508–519, https://doi.org/10.1016/J.RENENE.2020.11.107.
[72] M.T. Rashid, M.A. Jatoi, B. Safdar, A. Wali, R.M. Aadil, F. Sarpong, H. Ma, Modeling the drying of ultrasound and glucose pretreated sweet potatoes: The impact on phytochemical and functional groups, Ultrasonics Sonochemistry 68 (2020) 105226, https://doi.org/10.1016/j.ultsonch.2020.105226.
[73] F. Ren, C.A. Perussello, Z. Zhang, J.P. Kerry, B.K. Tiwari, Impact of ultrasound and blanching on functional properties of hot-air dried and freeze dried onions, LWT 87 (2018) 102–111, https://doi.org/10.1016/J.LWT.2017.08.053.
[74] Food Safety and Standards Authority of India 13 (2018).
[75] A. Reyes, V. Bubnovich, R. Bustos, M. Vásquez, R. Vega, E. Scheuermann, Comparative study of different process conditions of freeze drying of 'Murtilla'berry, Drying Technology 28 (12) (2010) 1416–1425, https://doi.org/10.1080/07373937.2010.482687.
[76] M. Rezaie, R. Farhoosh, M. Iranshahi, A. Sharif, S. Golmohamadzadeh, Ultrasonic-assisted extraction of antioxidative compounds from Bene (Pistacia atlantica subsp. mutica) hull using various solvents of different physicochemical properties, Food Chemistry 173 (2015) 577–583, https://doi.org/10.1016/J.FOODCHEM.2014.10.081.
[77] M.M. Rob, K.-N. Hisashi, Study of the allelopathic activity of "*Garcinia pedunculata*" Roxb, Plant Omics 12 (1) (2019) 31–36.
[78] Ó. Rodríguez, V. Eim, C. Rosselló, A. Femenia, J.A. Cárcel, S. Simal, Application of power ultrasound on the convective drying of fruits and vegetables: effects on quality, Journal of the Science of Food and Agriculture 98 (5) (2018) 1660–1673, https://doi.org/10.1002/JSFA.8673.
[79] M. Rodriguz, R.G. von Gioi, Affine Invariant Image Comparison under Repetitive Structures, Proceedings - International Conference on Image Processing, ICIP 1203–1207 (2018), https://doi.org/10.1109/ICIP.2018.8451060.
[80] Rodríguz Mariano, & von Gioi Rafael Grompone. (2018b). 2018 IEEE International Conference on Image Processing : proceedings : October 7-10, 2018, Megaron Athens International Conference Centre, Athens, Greece. https://doi.org/https://doi.org/10.1109/ICIP.2018.8451060.
[81] Romero J., C. A., & Yépez V., B. D. (2015). Ultrasound as pretreatment to convective drying of Andean blackberry (Rubus glaucus Benth). Ultrasonics Sonochemistry, 22, 205–210. https://doi.org/10.1016/j.ultsonch.2014.06.011.
[82] M. Roy, M.A.I. Bulbul, M.A. Hossain, J.H. Shourove, S. Ahmed, A. Sarkar, R. Biswas, Study on the drying kinetics and quality parameters of osmotic pre-treated dried Satkara (Citrus macroptera) fruits, Journal of Food Measurement and Characterization 1–15 (2022), https://doi.org/10.1007/S11694-021-01177-1.
[83] R. Sakooei-Vayghan, S.H. Peighambardoust, J. Hesari, D. Peressini, Effects of osmotic dehydration (with and without sonication) and pectin-based coating pretreatments on functional properties and color of hot-air dried apricot cubes, Food Chemistry 311 (2020) 125978, https://doi.org/10.1016/j.foodchem.2019.125978.
[84] F. Salehi, M. Kashaninejad, Modeling of moisture loss kinetics and color changes in the surface of lemon slice during the combined infrared-vacuum drying, Information Processing in Agriculture 5 (4) (2018) 516–523, https://doi.org/10.1016/j.inpa.2018.05.006.
[85] A. Sarkar, S. Rahman, M. Roy, M. Alam, M.A. Hossain, T. Ahmed, Impact of blanching pretreatment on physicochemical properties, and drying characteristics of cabbage (Brassica oleracea), Food Research 5 (2) (2021) 393–400. https://doi.org/10.26656/fr.2017.5(2).556.
[86] S.K. Sarker, S.S. Sonet, M. Mohasinul Haque, M. Sharmin, Disentangling the role of soil in structuring tropical tree communities at Tarap Hill Reserve of Bangladesh, Ecological Research 28 (4) (2013) 553–565, https://doi.org/10.1007/s11284-013-1045-x.
[87] Scientific Criteria to Ensure Safe Food. (2003). National Academies Press (US), Washington (DC) Appendix E, International Microbiological Criteria.
[88] B. Tomadoni, L. Cassani, G. Viacava, M.D.R. Moreira, A. Ponce, Effect of ultrasound and storage time on quality attributes of strawberry juice, Journal of Food Process Engineering 40 (5) (2017) e12533.
[89] D. Torreggiani, G. Bertolo, Osmotic pre-treatments in fruit processing: chemical, physical and structural effects, Journal of Food Engineering 49 (2–3) (2001) 247–253, https://doi.org/10.1016/S0260-8774(00)00210-7.
[90] A. Vega-Gálvez, K. Ah-Hen, M. Chacana, J. Vergara, J. Martínez-Monzó, P. García-Segovia, R. Lemus-Mondaca, K. di Scala, Effect of temperature and air velocity on drying kinetics, antioxidant capacity, total phenolic content, colour, texture and microstructure of apple (var. Granny Smith) slices, Food Chemistry 132 (1) (2012) 51–59, https://doi.org/10.1016/J.FOODCHEM.2011.10.029.
[91] J. Wang, L. Fan, Effect of ultrasound treatment on microbial inhibition and quality maintenance of green asparagus during cold storage, Ultrasonics Sonochemistry 58 (2019) 104631, https://doi.org/10.1016/J.ULTSONCH.2019.104631.
[92] W. Weibull, A statistical distribution function of wide applicability, Journal of Applied Mechanics. (1951).
[93] W. Zzaman, R. Biswas, M.A. Hossain, Application of immersion pre-treatments and drying temperatures to improve the comprehensive quality of pineapple (Ananas comosus) slices, Heliyon 7 (1) (2021) e05882.