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Research Article

Microwave-Assisted Hot Air Drying of Orange Snacks: Drying Kinetics, Thin Layer Modeling, Quality Attributes, and Phenolic Profiles

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Citrus fruits, regarded as a prominent fruit crop, are cultivated extensively around the globe and orange (*Citrus sinensis* L.) is a widely cultivated popular member of the citrus family. Dried oranges have gained recognition as a healthy snack option among consumers and worldwide markets due to the absence of additional ingredients such as sugar and chemicals, whilst yet containing significant natural beneficial components. The drying method is very intriguing due to its ability to facilitate the efficient production, packaging, storage, and transportation of dried oranges at a cost-effective price. In this study, the effects of microwave pretreatment (Mpt) (90 W, 30 min) on hot air drying (HTAD-MW) (60, 70, and 80°C) were investigated, along with the effects on the drying kinetics, rehydration capacity, and quality properties of the orange snack including phenolic compounds (vanillic acid, gallic acid, epicatechin, hesperidin, naringenin, chlorogenic acid, sinapic acid, and *o*-coumaric acid), antioxidant capacities (with DPPH, FRAP, and CUPRAC methods), and ascorbic acid contents. For modeling the kinetics of orange snack drying in all tests, logarithmic, Wang and Singh's, diffusion approach, two term, and Wang and Sing's models performed best. Hot air drying (HTAD) at 70°C applied orange snacks showed the lowest $\triangle E^*$ab value, and the color values were close to those of fresh orange slices. The levels of total and individual phenolics, antioxidant capacity (AC), and ascorbic acid (AA) in dried orange snacks were found to be significantly lower ($p < 0.05$) than in the fresh orange slices. Results also showed that HTAD-MW-applied orange snacks contained more total phenolic (TP) content, individual phenolic content, and AC but lower AA than HTAD-applied samples. The highest amount of phenolic compound was hesperidin for fresh and dried orange snacks. The method that best preserves the TP content and AC of dried orange snacks was found at the drying condition of HTAD-MW at 60°C. As a conclusion, it was suggested that the use of microwave and hot air combination is a promising method to introduce a new functional healthy snack to the dried product market with high quality.

1. Introduction

Citrus fruits, among the most important fruit crops, are cultivated in more than 140 countries throughout the world. The production of citrus in the world is 143 million tonnes of which 53.07% are oranges, 26.04% are tangerines, 14.28% are lemons, and 6.61% are grapefruits [1]. Citrus fruits are good source of pectins, vitamin C, and bioactive phytochemicals including flavonoids, coumarins, limonoids, carotenoids, and other compounds [2, 3]. Orange (*Citrus sinensis* L.), one of the most popular and extensively grown citrus families in the world [3], has an important role in our daily diet as it provides 12.5% of the daily fiber needs and has a cholesterol-lowering effect [4]. Furthermore, essential oils of orange including limonoids are molecules that both inhibit carcinogens and increase detoxification enzyme activity [5]. Additionally, oranges are rich in polyphenols, including flavonoids and phenolic acids. Polyphenols are secondary metabolites of plants with antioxidant, anti-inflammatory [6], antimicrobial [7], and anticarcinogenic [8] properties. They are predominantly analyzed by spectrophotometric methods. The Folin–Ciocalteu method, commonly employed for the determination of total phenolic content (TPC), not only targets phenolic compounds but also measures reducing components such as ascorbic acid, citric acid, simple sugars, and certain amino acids. Consequently, this method can yield values differing from the actual content of total phenolic compounds [9]. Considering all this, it becomes inevitable to quantify the amounts of polyphenols using chromatographic methods, owing to their selectivity and accuracy in determining the concentrations of those compounds.

Fresh fruits and vegetables with a moisture content (MtCt) of more than 80% are classified as perishable products. An efficient preservation method is required to extend the shelf life of the perishable orange fruit by preserving its nutritional and physical properties. The drying process is of great interest because dried orange can be easily produced, packaged, stored, and transported at a relatively low cost. Drying processes prevent the growth of some microorganisms responsible for spoilage of fresh crops by lowering MtCt of the final product [10]. Dried oranges have become a popular healthy snack alternative for consumers and global markets, as they do not contain extra ingredients such as sugar and additives and in contrast, possess important natural beneficial components. It is anticipated that the demand for snacks will continue to rise in the future, thereby creating a potential avenue for the development of novel food products. Currently, consumers are encouraged to have healthier lifestyles and to be more conscious of the food they consume. Although frequent snacking has been linked to unhealthy eating habits, a significant proportion (50%) of consumers now claim to prefer healthy snack options [11]. Consequently, there is a promising market prospect for snacks derived from dried fruits [12].

Previous findings in the literature have shown that drying methods affect the TP content, AC, and AA content of fruits and vegetables. Every drying technique has an adverse effect that varies depending on the characteristics of the materials. To maintain a product's functional properties as close as possible to those of the fresh products, it is critical to select and optimize the most suitable dehydration process for each product [13]. The most conventional drying method used in industrial drying of foods is HTAD with its large capacities and simplicity in the operation which leads to uniform dried product of good quality [14]. However, exposure to high temperatures in aerobic atmospheric conditions may cause a dramatic decrease in the concentration of bioactive and volatile compounds along with discoloration in the final dried products [15]. Microwave drying is an alternative drying method to conventional methods. It offers a short drying time, reduces energy, and distributes moisture uniformly. Additionally, microwave drying has the advantage of preserving the quality characteristics of the products including color, vitamins, minerals, and nutritional components [16]. However, microwave drying has some undesirable adverse effects due to overheating, thus textural damage on the final product can occur [17]. Those features result in limited application of the method.

The limitations associated with applications of hot air and microwave drying methods alone can be effectively solved by taking advantage of their combined applications. A dual-stage drying approach consisting of convective air drying and microwave drying has been demonstrated to enhance product quality while reducing both time and energy consumption [17, 18]. Convective air drying primarily targets surface water removal, whereas microwave energy facilitates the extraction of internal moisture content [19]. In studies reported in the literature, the influences of hot air, vacuum infrared and vacuum microwave [20], convective and microwave [21], and vacuum microwave and vacuum drying [22] methods on the drying kinetics and quality properties of oranges were compared. There are many reported studies in which microwave drying was used in combination with hot air to determine the drying kinetics of agricultural products including pumpkin slices [23], longan [24], spinach [25], lemon slices [26, 27], and okra [28]. In light of literature, it is very obvious that numerous investigations explored the utilization of convective drying techniques for orange fruit, although the direct application of the microwave drying method was notably scarce [29]. In some studies, the microwave was incorporated into the drying system as a preliminary treatment step [20, 30–32]. However, these endeavors predominantly focused solely on the drying kinetics of the orange fruit [30, 33, 34], with limited attention dedicated to parameters such as rehydration capacity, color attributes, and phenolic profiles characterized with chromatographic techniques. Investigating the synergistic effects of the innovative HTAD-MW approach on a diverse range of parameters including phenolics can yield useful results to formulate and produce high-quality, nutritionally enriched healthy dried orange snacks for consumers.

Consequently, in this study, the aim was to investigate the effect of microwave pretreatment (90 W, 30 min) on hot air drying conducted at different drying temperatures (60, 70, and 80°C) by evaluating the drying characteristics, rehydration capacity, and some quality attributes of dried

orange snacks including phenolic compounds (vanillic acid, gallic acid, epicatechin, hesperidin, naringenin, chlorogenic acid, sinapic acid, *o*-coumaric acid), antioxidant capacity (with DPPH, FRAP, and CUPRAC methods), and ascorbic acid content. In this context, this study will provide a holistic understanding of the proposed hybrid drying technique. Notably, the examination of individual phenolic components in orange snacks undergoing the combined microwave and hot air treatment represents a novel contribution to the field.

2. Material and Methods

2.1. Materials. The orange fruit (*Citrus sinensis* L.) fruits belonging to Valencia variety were obtained from Antalya, Turkey, for drying experiments. After being washed, they were sliced longitudinally with a diameter of 80 ± 2 mm and a thickness of 4 ± 0.5 mm without peeling. A digital moisture analyzer (MA150; Sartorius, Göttingen, Germany) was used to determine initial MtCt of the fresh orange samples as 5.33 g water/g dry matter (dm). Then, the orange slices were dried by placing them on a greaseproof paper. The weight of the samples was monitored periodically throughout the drying procedures via a digital scale (Mettler Toledo, MS3002S). The drying process was performed in three replications.

2.2. Drying Processes. For the hot air drying (HTAD) method, a cabinet dryer (Yücebaş Makine Analytical Equipment Industry Y35, Izmir, Turkey) with specifications of 200 W, 220 V, 50–60 Hz was used. The temperature and relative humidity of the dryer were controlled by sensors with an accuracy of ±2°C and ±2%, respectively. Drying was carried out using air with a relative humidity of 20%, temperatures of 60, 70 and 80°C, and a velocity of 0.2 m/s. The initial set air temperature and relative humidity were kept constant throughout the drying processing period by automatic adjustment features of the equipment.

In the hot air drying with Mpt method (HTAD-MW), 30 min of Mpt at 90 W power was performed prior to the HTAD. A standard household microwave oven (Bosch, HMT72G420, Munich, Germany) with parameters of 230 V, 50 Hz, and maximum 800 W was used for the microwave treatments. The device consists of a microwave application chamber with dimensions of 520 × 479 × 341 cm and a rotating glass plate with a diameter of 315 mm. After a 30 min Mpt period, HTAD was applied at 60, 70, and 80°C with a relative humidity of 20%.

The microwave pretreatment conditions and hot air drying temperatures were based on preliminary experimental results, our previous studies [13, 22], and important similar studies on drying of fruits and vegetables reported in the literature [20, 21, 29, 30, 32, 35, 36]. 90 W was chosen as the effective microwave power to obtain the best drying characteristics of orange slices without causing any burning of the products.

In particular, the integration of microwave pretreatment followed by hot air drying has been investigated in several studies on fruit and vegetables. These studies have consistently shown that this combined approach results in reduced drying times while maintaining high product quality, characterized by improved visual appeal and reduced nutrient degradation [17, 21, 30, 37, 38]. Therefore, the selection of an optimal drying temperature range between 60 and 80°C was assumed to reduce processing time while maintaining quality attributes.

Orange slices were dried with both HTAD and HTAD-MW until the MtCt reached 0.09 g water/g dm. Prior to further analysis, dried orange slices were vacuum-packed and stored in a freezer at −18 ± 0.5°C.

2.3. Modeling of Thin Layer Drying. The drying process is a combination of mass and heat transfer mechanisms. Understanding the parameters and conditions of this complex process is very important from an engineering point of view. Mathematical modeling allows the simulation of the operations on an industrial scale based on the experimental results obtained under laboratory conditions [22, 35, 39]. The mathematical models in Table 1, whose compatibility with experimental data has been frequently analyzed in the literature [35, 50], were selected for further statistical analysis within the scope of this study.

Equation (1) was used to compute the dimensionless moisture ratio (MR):

$$\mathrm{MR} = \frac{M_t - M_e}{M_i - M_e}, \tag{1}$$

where M_e denotes the equilibrium moisture level (g water g^{-1} dm), M_t denotes the MtCt at any time interval (g water g^{-1} dm), and M_i is the initial moisture content (g water g^{-1} dm). In drying of foodstuffs, the numerical value of M_e is significantly smaller compared to M_t and M_i. When MR is calculated in equation (1), it is suggested that the numerical value of M_e can be taken as zero [41].

DR of orange slices, in g water/g dm min, was calculated from equation (2) [40].

$$\mathrm{DR} = \frac{M_{t+\Delta t} - M_t}{\Delta t}, \tag{2}$$

where t is the drying time in minutes and $M_{t+\triangle t}$ represents the MtCt in in g water/g dm at any given moment.

The main criterion for selecting the most appropriate model was based on the coefficient of determination (R^2). Better goodness of fit is indicated by higher R^2, lower root mean square error (RMSE) (equation (3)) and chi square (χ^2) (equation (4)) values [51].

$$\mathrm{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\mathrm{MR}_{\mathrm{exp},i} - \mathrm{MR}_{\mathrm{pre},i}\right)^2\right]^{1/2}, \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(\mathrm{MR}_{\mathrm{exp},i} - \mathrm{MR}_{\mathrm{pre},i}\right)^2}{N - n}, \tag{4}$$

Table 1: Mathematical models applied to drying curves.

Model no	Model name	Equation	References
1	Page	$MR = \exp(-kt^n)$	[40]
2	Lewis	$MR = \exp(-kt)$	[41]
3	Logarithmic	$MR = a\ \exp(-kt) + c$	[42]
4	Henderson and Pabis	$MR = a\ \exp(-kt)$	[43]
5	Two term	$MR = a\ \exp(-k_0t) + b\ \exp(-k_1t)$	[44]
6	Two term exponential	$MR = a\ \exp(-kt)+(1-a)\ \exp(-kat)$	[45]
7	Wang and Singh	$MR = 1 + at + bt^2$	[46]
8	Diffusion approach	$MR = a\ \exp(-kt) + (1-a)\ \exp(-kbt)$	[47]
9	Verma et al.	$MR = a\ \exp(-kt) + (1-a)\ \exp(-gt)$	[48]
10	Midilli et al.	$MR = a\ \exp(-kt^n) + bt$	[49]

where N is the quantity of experimental data, $MR_{\text{exp},I}$ is the experimental MR at position i, $MR_{\text{pre},i}$ is the predicted MR at position i, and n is the quantity of model constants.

2.4. Determination of Effective Moisture Diffusivity (EMD). For long drying times, the EMD was calculated using Fick's second law (equation (5)) with the following assumptions being made: (i) mass transfer is symmetric; (ii) mass transfer is with respect to the center of the slice; (iii) initial MtCt is uniform; (iv) there is little external resistance; and (v) diffusion coefficient is constant [51]. Fick's law mathematical solutions for cylinder geometry are given in following equations:

$$\text{MR} = \sum_{n=1}^{\infty} \frac{4}{\mu_n^2} \exp\left(\frac{-\mu_n^2 \text{EMDt}}{r^2}\right), \tag{5}$$

$$\text{MR} = \frac{4}{\mu_1^2} \exp\ -\left(\frac{\mu_n^2 \text{EMDt}}{r^2}\right), \tag{6}$$

in which EMD denotes the effective moisture diffusivity (m^2s^{-1}), r represents the radius of the slice (m), n indicates the number of positive terms, μ is the Bessel function, and t is time (s). Equation (6) was transformed into a linear form, and EMD (equation (7)) was obtained by plotting ln (MR) over time using equation (8)'s slope (K). Equation (7), which was the intercept (y_0) of the associated expression (equation (9)), was used to determine the value of μ [52].

$$\ln(\text{MR}) = \ln\left(\frac{4}{\mu_1^1}\right) + \left[-\text{EMD}\left(\frac{\mu_1^2}{r^2}\right)\right]t, \tag{7}$$

$$K = \frac{\mu_1^2 \text{EMD}}{r^2}, \tag{8}$$

$$y_0 = \ln\left(\frac{4}{\mu_1^2}\right). \tag{9}$$

2.5. Rehydration Capacity. 5 g of dried samples were soaked in to the vessels containing 150 mL of distilled water at 30 and 60°C. Every 60 minutes, samples are taken out from the vessel followed by transferring them into a sieve to drain the water. After removing the surface water with a towel, samples were weighed. The process was continued until the constant mass was achieved [53].

Rehydration capacity (R) was calculated from the difference in sample weight between before and after rehydration according to the equation given below.

$$R = \frac{W_t - W_d}{W_d}, \tag{10}$$

where W_t is the mass (g) of the rehydrated sample when constant mass is reached and W_d is the mass of the dry sample. To ensure saturation, the samples were kept in water until no further changes in mass were observed.

2.6. Color Analysis. The surface color of fresh and dried orange slices was measured with a colorimeter (CR-5 Konica Minolta Chroma Meter, Osaka, Japan). The product is characterized by L^* value for lightness or darkness, a^* value for redness or greenness, and b^* value for yellowness or blueness factor. Chroma (C^*) and hue angle (h°) values represent the color intensity and color changes with the angles, respectively. After these parameters were measured by a colorimeter, the following equation was used to compute the total color difference (ΔE^*_{ab}), which was an indication of the changes occurred in the dried orange compared to its fresh form.

$$\Delta E^*_{\text{ab}} = \sqrt{\left(L^* - L_0^*\right)^2 + \left(a^* - a_0^*\right)^2 + \left(b^* - b_0^*\right)^2}, \tag{11}$$

where the color values of freshly cut orange slices are represented by L_0^*, a_0^*, and b_0^*.

$$C^* = \sqrt{\left(a^{*2} + b^{*2}\right)},$$
$$h^o = \arctan\left(\frac{b}{a}\right), \tag{12}$$

where h° ranges between 0° and 90° for positive a^* and b^* values, between 90° and 180° for positive b^* and negative a^* values, and between 180° and 270° for negative b^* and a^* values. Moreover, h° lies between 270° and 360° if b^* is negative and a^* is positive [54].

2.7. Extraction of Polyphenols and Antioxidants. The extraction of polyphenols and antioxidants in the fresh and dried orange slices was carried out using the method previously described by Kamiloglu and Capanoglu [54]. 2 ± 0.01 g of the sample was extracted with an extraction

solvent (5 mL of 75% aqueous methanol containing 0.1% formic acid). The extraction procedure was performed in a cooled ultrasonic bath for 15 min. Then, the mixture was centrifuged for 10 min at 2700*g*. Following collection of the supernatant, the extraction step was repeated two more times by adding the fresh extraction solvent to residual part of the sample. All three supernatants were combined and adjusted to a final volume of 15 mL. The final extracts were stored at −20°C until further analysis.

2.8. Determination of TP Content and AC. By using the Folin–Ciocalteu spectrophotometric method, the TP contents of fresh and dried orange slices were measured [55]. Gallic acid was used as a standard for the measurement of absorbance at 700 nm, and the amount of TP was reported as gallic acid equivalents (GAEq) per 100 g dry weight (mg GAEq/100 g dw).

DPPH (2,2-diphenyl-1-picrylhydrazyl), FRAP (ferric reducing antioxidant power), and CUPRAC (cupric reducing antioxidant capacity) assays were used to measure the AC of the orange slices [56–58]. The AC results were measured as μmol Trolox equivalent (TE) per gram dry weight. Each experiment was performed in triplicate.

2.9. Quantification of Polyphenols by HPLC. The amount of polyphenols was determined using a high-performance liquid chromatography-diode array detector (HPLC-DAD) as previously defined in the literature [59]. All extracted samples were passed through 0.45 μm membrane filters and injected into HPLC. A C18 column (25 cm × 4.6 mm, 5 μm; Sigma-Aldrich, Germany) was utilized. For spectral measurement at 280, 312, and 360 nm, the following solutions with flow rate of 1 mL/min and an injection volume of 10 μL were used: trifluoroacetic acid (TFAA)/ultrapure water (1 : 1000, v/v; eluent A) and TFAA/acetonitrile (1 : 1000, v/v; eluent B). The linear gradient was as follows: 0 min, 95% A and 5% B; 45 min, 65% A and 35% B; 47 min, 25% A and 75% B; 49 min, 65% A and 35% B; and 50 min, 95% A and 5% B. The column temperature was set at 45°C, and the temperature of the autosampler was maintained at 10°C. Column retention times and characteristic UV spectra were used to identify the polyphenols.

2.10. AA Content. The AA contents of fresh and dried orange slices were measured using the spectrophotometric method described by Akdaş and Başlar [50]. The technique is based on the decrease of 2,6-dichlorophenolindophenol via AA. First, 10 g of fresh and dried orange slices were extracted by 70 mL of oxalic acid (0.4%, w/v). 1 mL of the extracted filtrate was added to 9 mL of 2,6-dichlorophenolindophenol solution and measured by a spectrophotometer at 520 nm. Results were shown as mg AA/100 g dm.

2.11. Statistical Analysis. All analyses were performed in triplicate. The statistical analyses were performed using IBM SPSS Statistics 23.0 software, and the results were expressed as means ± standard deviation. The findings of the measurements were subjected to an analysis of variance (one-way ANOVA). The presence of significant differences ($p < 0.05$) between means was determined using Duncan's multiple range tests.

A multivariate analysis approach, known as principal component analysis (PCA), was utilized in this study to identify the phenolic profile, AA content, TP content, and AC that differentiate the various groups under investigation. All statistical analyses were conducted using IBM SPSS Statistics 23.0 software.

Ten empirical and semi-empirical thin layer drying equations, which are mentioned in Table 1, were applied in this study. In order to estimate the drying constants and coefficients, nonlinear regression analyses of these equations were performed using MATLAB R2022b with Curve Fitting Toolbox (MathWorks Inc., MA).

3. Results and Discussion

3.1. Drying Kinetics. Variations in MtCt against drying time of orange slices at different drying conditions are illustrated in Figure 1. According to the experimental findings, drying times were shortened by raising the drying temperature both for HTAD and HTAD-MW. The long drying period was yielded from HTAD at 60°C (600 min), while HTAD-MW at 80°C shortened the period most (215 min). HTAD-MW application shortened drying time at all drying temperatures compared to HTAD method. Based on those findings, it was shown that the drying temperature and the use of Mpt reduced the time required to reach the acceptable level of MtCt of the final dried product. This trend was also observed in our previous research [22]. Talens et al. [34] dried dietary fibers derived from orange peel using hot air and hot air–microwave combined methods. The findings of this study are compatible with those of our results. It was concluded that when combined method was used, the drying time reduced by 92% when compared with the HTAD method used alone.

The drying rates versus the MtCt are displayed in Figure 2. The lowest and highest DR values were observed as 0.154 and 0.488 g water/g·dm·min for 60°C HTAD and 80°C HTAD-MW techniques, respectively. Using Mpt before HTAD resulted in higher DR values than those when HTAD alone was used. The increment was 16.23%, 14.88%, and 67.69% for the temperatures of 60°C, 70°C, and 80°C, respectively. This may be the result of the rapid development of mass and heat transport mechanisms [60]. Drying applications of 60°C HTAD-MW and 70°C HTAD increased the drying rate by 16.23% and 70.13%, respectively, compared to 60°C HTAD. According to the results, it may be concluded that temperature had a considerably greater impact on the drying rate than microwave power. During the drying process for HTAD-MW, the drying rate of the samples increased until the upper temperature limit set was achieved, and after reaching this threshold, the drying rates decreased continuously following a path at a constant temperature since the maximum temperature could not increase further. Similar results were observed for microwave-assisted processing of sliced apples [61]. With the application of HTAD

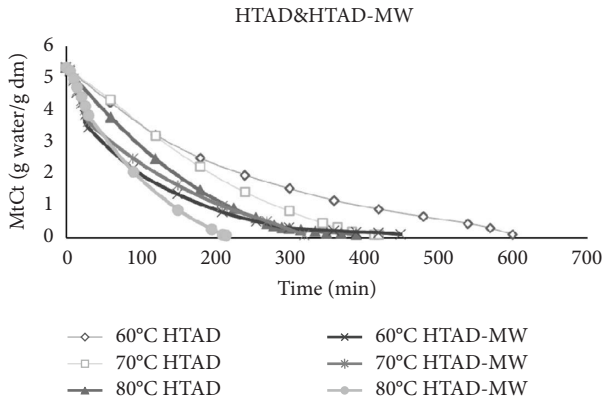

Figure 1: HTAD and HTAD-MW drying curves of orange snacks on dry basis.

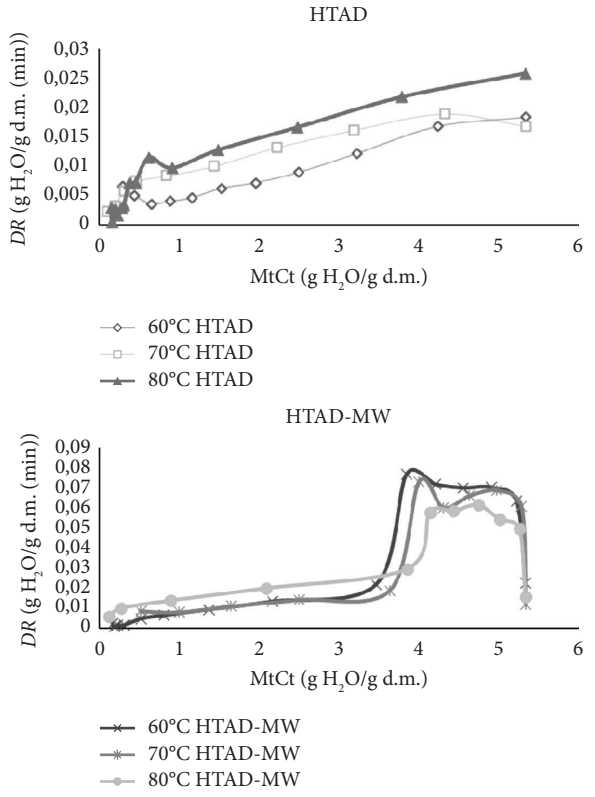

Figure 2: *DR* against MtCt for orange snacks dried with HTAD and HTAD-MW methods.

techniques, DR steadily decreased; no period of increasing or constant rate was seen. Those results were consistent with the findings reported by Horuz et al. [60]. The absence of a constant velocity period in HTAD was attributed to the thin layer formation of the sample. Owing to fact that the drying process was primarily driven by diffusion, the layer formation could not supply a constant amount of water.

3.2. Mathematical Modeling of Drying Curves. Using ten different thin layer drying models described in Table 1, the drying kinetics of orange snacks were investigated. Table 2 provides the model coefficients and the indicator values that show better goodness of fit for the models (R^2, χ^2, and RMSE values). R^2, RMSE, and χ^2 values varied from 0.8560 to 0.9997, 0.005453 to 0.173400, and 0.000030 to 0.04373, respectively. Based on the highest R^2, the lowest χ^2, and RMSE values, the appropriate model for characterizing the drying kinetics of orange snacks was chosen. Thus, the logarithmic model for 60°C HTAD and Wang and Sing model for 70 and 80°C HTAD applications proved to be the best fitted methods. Additionally, for HTAD-MW method, diffusion approach, two term, and Wang and Sing methods were chosen as the best models explaining the drying kinetics of orange snacks. These models were validated as the most appropriate model for defining the drying curve of many agricultural crops dried in thin layers, including bell peppers [39], orange slices [20], cocoa beans [62], nutmeg mace [63], and apricots [64].

3.3. EMD. The effect of different drying conditions on EMD values of orange snacks are represented in Figure 3.

Among the drying conditions applied within the scope of the study, HTAD-MW at 80°C received the greatest EMD value ($5.712 \times 10^{-7}\ m^2 s^{-1}$), while HTAD at 60°C condition achieved the lowest ($1.7745 \times 10^{-7}\ m^2 s^{-1}$). As the temperature rose, EMD levels increased. Moreover, Mpt had a positive impact on diffusivity. The increase in air temperature led to a rise in heat transfer rate throughout the orange snacks. Therefore, mass transfer was comparatively high during the constant rate period [65]. In fact, the microwave-pretreated sample dried at the lowest temperature (60°C) had a higher EMD value than the one dried at the highest temperature (80°C) without pretreatment. This result showed that Mpt was more effective on the EMD value than drying temperature. It can be attributed to the microwave energy that speeds up the rotation of water molecules. Consequently, an increase in the kinetic energy of the water molecules enables the diffusion of water to the surface of the food followed by evaporation [66]. Similarly, previous studies in the literature revealed that the EMD values increased with rising temperatures during the drying processes of orange slices [29], orange peel [67], and mint leaves [68].

3.4. Rehydration Capacity. The amount and ratio of water absorption are crucial factors for reconstituting of dried foods, as they strongly influence the preparation time of the dried foods in addition to the sensory qualities of the final product. The rehydration characteristics of a dehydrated product are recognized as a quality indicator, as they reveal the physical and chemical alterations that occurred during dehydration [69].

The rehydration capacities of dried orange snacks were assessed at 30 and 60°C. Figure 4 shows the rehydration curves. For the temperatures of 30 and 60°C, the rehydration processes finalized after 660 and 480 minutes, respectively. Water absorption increased throughout the rehydration process at each condition until the saturation point was reached. This can be explained by the absorption of a substantial amount of water during the initial stages of the rehydration process followed by

Table 2: Statistical data obtained from the examined drying models.

Model no			60°C HTAD	70°C HTAD	80°C HTAD	60°C HTAD-MW	70°C HTAD-MW	80°C HTAD-MW
1	Model coefficient	n	1.086	1.489	1.354	0.8901	0.9161	1.192
		k	0.00265	0.000401	0.00121	0.01665	0.01318	0.00495
	R^2		0.9969	0.9971	0.9981	0.9960	0.9904	0.9962
	RMSE		0.01817	0.01961	0.01316	0.02567	0.03697	0.0261
	χ^2		0.00039	0.00047	0.00019	0.00075	0.00164	0.00082
2	Model coefficient	k	0.004302	0.005741	0.007898	0.01014	0.008933	0.01155
	R^2		0.9949	0.9611	0.9779	0.9927	0.9879	0.9879
	RMSE		0.0222	0.0684	0.04339	0.03342	0.0397	0.04452
	χ^2		0.00054	0.00515	0.00202	0.00119	0.00172	0.00216
3	Model coefficient	k	0.003639	0.003114	0.005818	0.01082	0.008526	0.08531
		a	1.074	1.402	1.152	0.9616	0.9886	1.19
		c	−0.07695	−0.3829	−0.1314	0.02824	−0.005879	−0.1723
	R^2		0.9986	0.9978	0.9951	0.9944	0.9886	0.9987
	RMSE		0.01271	0.01831	0.02214	0.03135	0.0425	0.01582
	χ^2		0.00022	0.00046	0.00061	0.00121	0.00241	0.00033
4	Model coefficient	k	0.004374	0.006083	0.008168	0.008662	0.009721	0.0125
		a	1.017	1.075	1.052	0.9839	0.9790	1.049
	R^2		0.9954	0.9678	0.9808	0.9886	0.9934	0.9926
	RMSE		0.02223	0.06565	0.04201	0.04039	0.0329	0.03637
	χ^2		0.00059	0.00527	0.00204	0.00196	0.00124	0.00159
5	Model coefficient	k_0	0.004372	0.007152	0.006472	0.009645	0.007706	0.0133
		k_1	0.004374	0.6569	0.006445	0.009616	0.05605	0.1569
		a	0.3979	1.31	18.65	−0.7844	0.8866	1.094
		b	0.6189	−0.3101	−17.81	1.757	0.1438	−0.09262
	R^2		0.9954	0.9863	0.9302	0.9933	0.9925	0.9949
	RMSE		0.02493	0.0486	0.08707	0.03574	0.03651	0.03385
	χ^2		0.00093	0.00371	0.01034	0.00170	0.00199	0.00172
6	Model coefficient	k	0.9992	90.24	1	0.02841	0.06249	0.01606
		a	0.004287	$6.361e-05$	0.007853	0.2663	0.119	1.73
	R^2		0.9947	0.9611	0.9771	0.9967	0.9904	0.9958
	RMSE		0.02379	0,07212	0.04592	0.02323	0.03705	0.02744
	χ^2		0.00068		0.00243	0.00062	0.00165	0.00090
7	Model coefficient	a	−0.003242	−0.003866	−0.005324	−0.006127	−0.006622	−0.008437
		b	$2.804e-06$	$3.577e-06$	$7.253e-06$	$9.199e-06$	$1.165e-05$	$1.816e-05$
	R^2		0.9911	0.9989	0.9997	0.9582	0.9701	0.9976
	RMSE		0.03087	0.0124	0.005453	0.08286	0.06534	0.02098
	χ^2		0.00114	0.00019	0.000030	0.00785	0.00512	0.00053
8	Model coefficient	k	0.00628	0.003308	0.01371	0.03129	0.04821	0.1609
		a	$1.094e-07$	15.46	$8.082e-10$	0.2219	0.09864	−0.09364
		b	0.685	0.9629	0.5761	0.2522	0.1622	0.08255
	R^2		0.9949	0.9819	0.9779	0.9968	0.9915	0.9949
	RMSE		0.02454	0.05233	0.04503	0.02395	0.03664	0.03192
	χ^2		0.00080	0.00377	0.00253	0.00071	0.00179	0.00136
9	Model coefficient	k	0.004291	0.007152	0.009451	0.03433	0.007817	0.01328
		a	0.4997	1.31	1.301	0.2152	0.9006	1.093
		g	0.004313	0.6385	0.5523	0.007643	0.04782	0.1649
	R^2		0.9949	0.9863	0.9932	0.9965	0.9915	0.9949
	RMSE		0.02454	0.04546	0.02611	0.02412	0.03664	0.03192
	χ^2		0.00080	0.00284	0.00085	0.00078	0.00179	0.00136
10	Model coefficient	n	−4.046	0.2585	0.5036	0.3301	10.55	−7.304
		k	7.812	0.6111	0.5469	0.06782	2.611	5.944
		a	0.8813	2.755	1.004	0.847	0.9096	3.704
		b	−0.001461	−0.002306	−0.002432	−0.002147	−0.002306	−0.004571
		t	3.192	10.03	0.142	0.4366	0.4708	1.222
	R^2		0.9211	0.9672	0.9004	0.8560	0.9672	0.9713
	RMSE		0.110000	0.081100	0.10910	0.17340	0.08118	0.08581
	χ^2		0.020740	0.012060	0.01785	0.04373	0.01129	0.01262

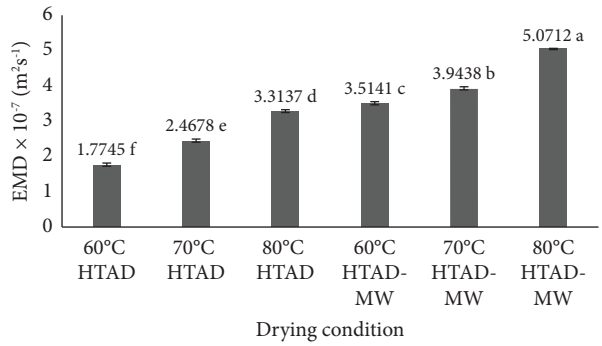

Figure 3: EMD values of orange snacks.

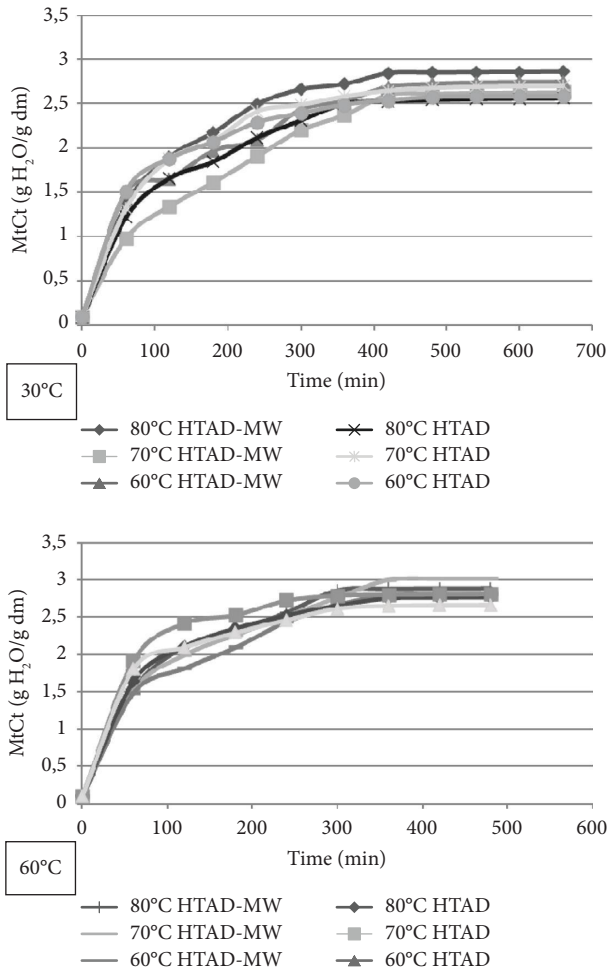

Figure 4: Effect of HTAD and HTAD-MW techniques on rehydration capacity of dried orange slices rehydrated at 30°C and 60°C.

diffusion of the water into capillaries and cavities occurred near to the surface [70]. In the final stage of the rehydration, a steady rate of the rehydration capacity was achieved. This can be explained by the decrease in water absorption rate that occurs when the rehydration process is almost at equilibrium. In comparison to other drying methods, HTAD-MW at 70°C led to the maximum rehydration capability of dried orange snacks with a final MtCt of 3.02 g H_2O/g d.m. The application of microwave pretreatment improved the rehydration capacity of dried orange snacks. This improvement might result from the intercellular configuration that microwave energy creates, allowing for large amounts of water to be absorbed during rehydration [60]. In terms of temperature, rehydration at 60°C enhanced the ultimate MtCt of dried orange snacks compared to rehydration at 30°C. Due to the impact of temperature on cell walls and tissue, the rehydration capacity increased as the rehydration water temperature increased. The structure of dried samples at 60°C is more porous than that at 30°C, allowing for greater water absorption. Aral and Beşe [71] found similar results when they rehydrated dried hawthorn fruit at 50 and 70°C. Additionally, it was determined that the combined method (HTAD-MW) enhanced the rehydration capacity of dried oranges regardless of the drying temperatures. Furthermore, similar results were also obtained by Maskan [69] for dried kiwi samples.

3.5. Color Properties. Color characteristic is a crucial quality attribute of a foodstuff for obtaining consumer acceptance [72]. Table 3 compares the color parameters of orange snacks dried at different conditions. The L^* values (that indicate lightness-darkness) of dried orange snacks showed a decline ranged between 9.89% and 26.11% for 60°C HTAD and 80°C HTAD-MW, respectively. In other words, dried orange snacks were noticeably darker than the fresh orange slices. This trend was also observed by Ozkan-Karabacak et al. [73] and Sonkar and Immanuel [74] for dried kumquat and orange pestil, respectively. This phenomenon was attributed to the degradation of carotenoids and the browning reactions. In addition, lower L^* values were observed as a result of HTAD-MW when compared with HTAD. During combined drying of microwave and hot air, orange snacks may get internally carbonized due to extreme heat accumulation [75].

The measured a^* values (which indicate red-green) of dried samples were within the range of 17.77 – 15.82 (Table 3) and the original sample had a^* value of 15.67. It was found that dried a^* value of the dried orange snacks' increased in comparison to that of the fresh orange slices. The increase in a^* value with an increase in drying temperature was due to the overheating of the orange slices with a heat-sensitive feature. Additionally, the a^* value was relatively high at 80°C HTAD-MW, the shortest drying method. The penetration of microwave energy resulting in excessive amount of heat in the product caused an increment of the a^* value [21]. The b^* value (that indicates yellow-blue) decreased the most for the sample dried at 80°C HTAD-MW (40.24% decrement), compared to that of fresh orange slices. It can be explained with the color change of the fruit from bright and orange to dull and dark red throughout the drying process [74].

The color variation (ΔE^*_{ab}) in food products throughout a process was found to range between 13.87 and 20.20 for dried orange snacks. As the samples dried by HTAD at 70°C obtained the lowest ΔE^*_{ab} value, their color values were close to fresh fruit.

Table 3: The color values of fresh and dried orange slices changed by using the HTAD and HTAD-MW procedures.

Drying conditions	L^*	a^*	b^*	ΔE^*_{ab}	C^*	h°
Fresh orange slices	56.49 ± 0.07^a	15.67 ± 0.01^g	46.99 ± 0.08^a	—	49.54 ± 0.08^a	$71.55 \pm 0{,}04^a$
60°C HTAD	50.90 ± 0.05^b	15.82 ± 0.01^f	42.15 ± 0.02^b	17.23 ± 0.01^c	46.48 ± 0.01^b	68.08 ± 0.02^b
60°C HTAD-MW	49.53 ± 0.03^c	15.93 ± 0.02^e	41.20 ± 0.03^c	20.20 ± 0.05^a	43.08 ± 0.05^c	65.93 ± 0.01^c
70°C HTAD	46.01 ± 0.04^d	16.28 ± 0.05^d	38.09 ± 0.08^d	13.87 ± 0.01^f	40.23 ± 0.02^d	64.87 ± 0.02^e
70°C HTAD-MW	44.35 ± 0.01^e	16.71 ± 0.01^c	31.47 ± 0.06^e	19.84 ± 0.03^b	34.96 ± 0.09^e	65.06 ± 0.03^d
80°C HTAD	43.04 ± 0.03^f	17.28 ± 0.06^b	30.75 ± 0.12^f	14.57 ± 0.01^e	33.78 ± 0.25^f	63.79 ± 0.03^f
80°C HTAD-MW	41.74 ± 0.05^g	17.77 ± 0.05^a	28.08 ± 0.03^g	16.20 ± 0.02^d	30.64 ± 0.03^g	62.87 ± 0.05^g

Note. Different lower case letters indicate significant differences in the same column ($p < 0.05$).

The purity or saturation of a color can be determined by chroma (C^*) value, a chromaticity measurement. During the drying process, the C^* values of orange slices tended to decrease. The most saturated color was obtained by HTAD at 60°C application in all drying conditions.

There is a strong correlation between the perception of the color by consumers and the hue angle value, which is consequently regarded as a qualitative characteristic of color [76]. The orange color of orange fruits (both peel and flesh) essentially comes from carotenoids and is characterized by a higher hue angle. Fresh samples gave a higher h° value than dried orange snacks.

As the drying temperature of sliced oranges decreased, the ΔE^*_{ab} value increased under both HTAD and HTAD-MW drying conditions. Similarly, the maximum C^* and h° values were obtained when the drying temperature of sliced oranges decreased. The observed reduction in C^* value during drying likely contributes to the ΔE^*_{ab}, with lower C^* values in dried samples leading to a higher ΔE^*_{ab}, indicating a more noticeable shift in color from the fresh fruit, thus emphasizing the strong correlation between h°, C^* and ΔE^*_{ab} in assessing the visual appearance of dried orange snacks.

Additionally, Figure 5 visually presents the impact of drying conditions on the physical characteristics of orange slices. Figure 5 also displays the development of a brown color in orange snacks that have been dried at higher temperatures. Orange snacks dried HTAD and HTAD-MW at 60°C appears to have a more consistent color and structure. However, distinguishing the intensity of the dark color among orange snacks dried under different conditions is challenging due to the limitations of the image quality.

3.6. Ascorbic Acid Content. Due to its heat and light sensitivity, ascorbic acid is a crucial nutrient for humans and a sign of the quality of dried food products [77]. Figure 6 illustrates the influence of the drying treatments on the AA content of orange slices. It can be concluded from Figure 6 that the AA content of orange snacks dried under different conditions showed a considerable decrease. After the drying process, the initial amount of AA (45.18 mg/100 g) in oranges degraded between 56.64% (for HTAD at 80°C) and 61.73% (for HTAD-MW at 60°C).

Figure 6 demonstrated that decreasing the drying temperature from 80°C to 60°C caused more AA degradation in samples dried under HTAD conditions. The samples dried by HTAD-MW showed a similar trend. This might be due to the AA oxidation occurring at the prolonged drying conditions. Those findings are coherent with the study conducted by Zahoor and Khan [77], in which the heat application had a significantly negative effect on AA content of bitter gourd dried by convective and microwave-assisted convective drying methods. Moreover, the greater decrease in AA content during HTAD-MW than HTAD may be due to their deterioration by higher heat production occurring by microwave power [78].

3.7. TP Content and AC. Figure 7 demonstrates the TP content of the fresh and dried orange slices. The levels of TP content of dried samples were in the range of 606.02 and 809.17 mg GAEq/100 g·dw. While the minimum reduction in TP content was obtained as 34.64% after HTAD-MW drying applications at 60°C, the maximum reduction in TP content was obtained as 51.05% under 80°C HTAD conditions (Figure 7).

The decreases of TP content were enhanced by the increment of drying temperature, which could be due to the enzymatic processes, phenol–protein connection, degradation of phenolic compounds with higher temperatures, and longer drying times [79]. Some of the researchers reported that degradation of phenolics is linked with thermal treatments [80]. In contrast, an increase in the TP content and AC after drying has also been reported in dried fruits and vegetables such as kiwi and pepino [78], onions [81], and orange peel [82].

TP content losses after drying were reduced with the application of microwave in combination with hot air. The better preservation of TP content using HTAD-MW method compared to the HTAD application is probably due to the release of the phenolic components from the food matrix [83]. This could also be related to the shortened drying time with the application of microwave as a pretreatment before HTAD, and therefore the less exposure of the orange slices to the heat. In addition, it can be explained by that microwave energy causes the formation of new Maillard reaction components which have high phenolic content [84, 85]. This outcome was in agreement with that found by Şahin et al. [86], who investigated the effect of microwave, freeze, vacuum, oven, and ambient air drying techniques on TP content, AC, and flavonoid content of olive leaves.

The antioxidant capacities of the fresh and dried orange slices are given in Figure 7. The antioxidant capacity of the fresh and dried orange slices was determined using three different

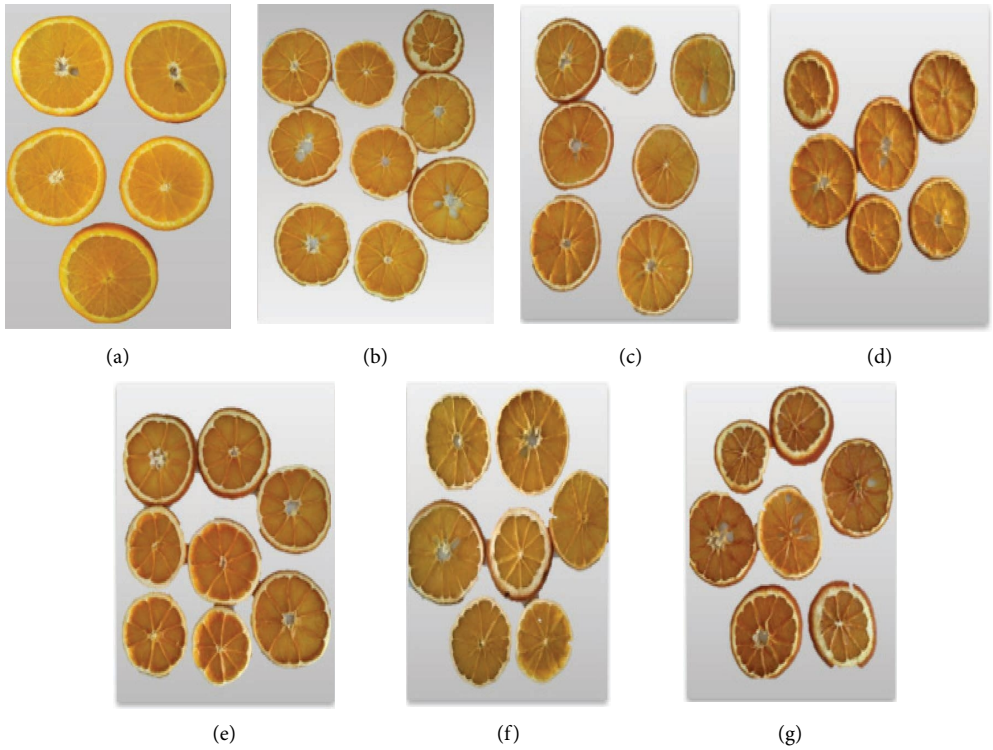

Figure 5: Images of a fresh orange slices (a), dried by 60°C HTAD (b), 60°C HTAD-MW (c), 70°C HTAD (d), 70°C HTAD-MW (e), 80°C HTAD (f), and 80°C HTAD-MW (g).

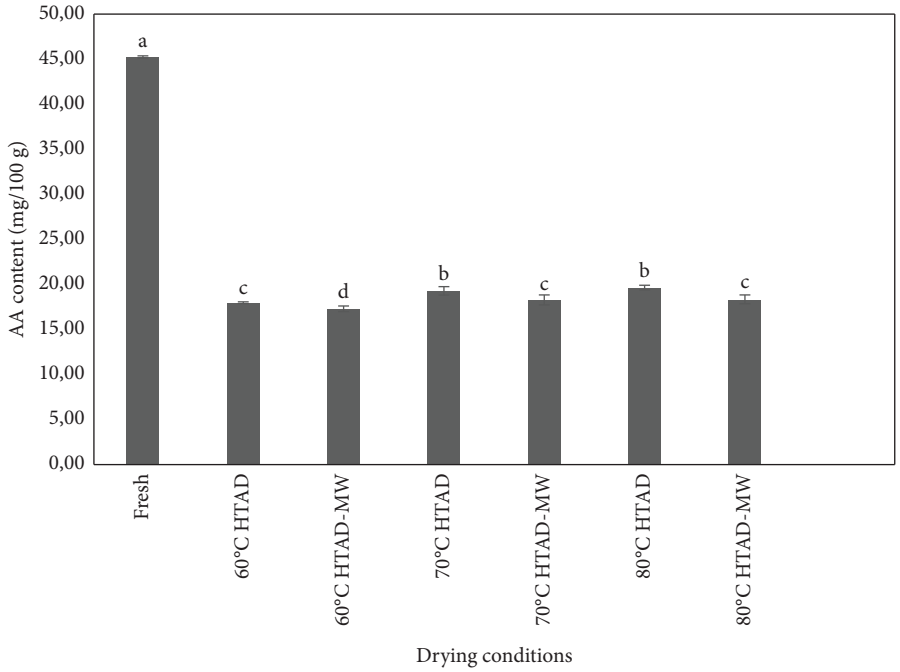

Figure 6: AA content of orange slices as a result of various drying conditions. *Note*. Different lower case letters indicate significant differences in bars ($p < 0.05$).

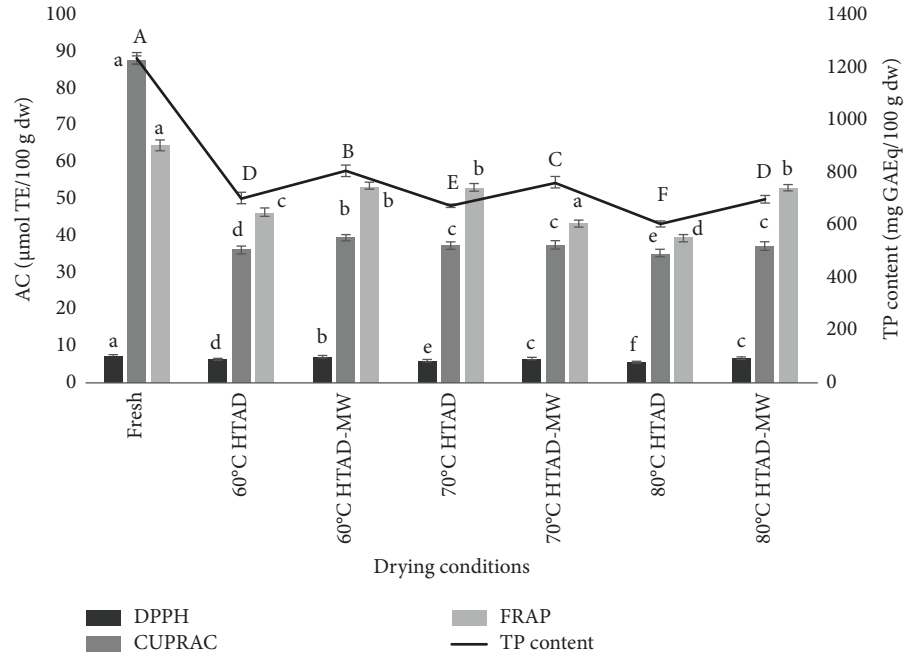

Figure 7: The differences in TP content and AC of fresh and dried orange slices. *Note*. Different lower case and upper case letters indicate significant differences ($p < 0.05$) in bars and lines, respectively.

assays, namely, DPPH, FRAP, and CUPRAC. AC of the dried orange snacks from the different types of assays was in the following order FRAP > CUPRAC > DPPH. Since the complex structure of phytochemical and oxidative processes cannot be understood with a single test mechanism, different types of assays need to be applied to determine AA [87]. Similar results (FRAP > CUPRAC > DPPH) were obtained in a study comparing the total antioxidant capacity of homemade tomato sauce with industrial processing [88]. The results of the FRAP and CUPRAC methods were found to be about ten times higher than the results of the DPPH method. This is possibly because the DPPH method only measures hydrophobic antioxidants, whereas the CUPRAC method evaluates both hydrophilic and hydrophobic antioxidants and the FRAP method measures hydrophobic antioxidants [9].

Similar to TP content results, the drying process significantly decreased the AC of orange slices ($p < 0.05$). The reduction ratio changed between 17.13 – 39.21%, 54.87–59.68%, and 6.71–25.53% for FRAP, CUPRAC, and DPPH assays, respectively. Bioactive substances may break down through enzymes, chemical compounds, or high-temperature thermal treatments, which could account for the decrease in AC after drying [89, 90]. Garau et al. [91] reported that the AC of orange peel and pulp similarly reduced by air drying. In contrast, Vega-Gálvez et al. [92] reported that the radical scavenging activity of red pepper was higher after air drying than that of fresh red pepper. Studies investigating the effects of drying processes on the antioxidant activity of vegetables revealed inconsistent results due to a variety of factors, including drying techniques, types of extraction solvents, antioxidant assays, and interactions between various antioxidant reactions [92].

The AC of the dried orange snack, as measured using all three assays, was retained the most by the 60°C HTAD-MW and degraded to the highest extent with the 80°C HTAD techniques.

The results indicate that HTAD without microwave pretreatment has a destructive effect on antioxidant compounds. Using microwave power prior to HTAD shortened the exposure to oxygen and resulted in lower degradation of AC values for orange snacks.

Correlation coefficients between TP content and AC assays (DPPH, CUPRAC, and FRAP) are shown in Table 4. TP content and CUPRAC ($R^2 = 0.935$) had the strongest correlation, which was followed by TP content and DPPH ($R^2 = 0.736$). Additionally, it showed a moderately linear relationship between TP content and FRAP ($R^2 = 0.646$). Among AC assays, the highest correlation was observed between CUPRAC and FRAP assays ($R^2 = 0.6042$). The variance in correlation coefficient between the various antioxidant assays points to the possibility that the overall antioxidant capacity cannot be evaluated using a single antioxidant assay. Therefore, a variety of assays using various mechanisms were strongly advised in order to fully comprehend the outcomes [93]. Furthermore, it is widely acknowledged in the earlier studies that the Folin–Ciocalteu method is not particular to TP content analysis. Reducing substances such as citric acid, ascorbic acid, simple sugars, or certain amino acids can impact the analysis and lead to an overestimation of the concentration of phenolics [9]. Moreover, these results agreed with those of other published works, and a positive correlation between TP content and AC was observed [94]. Due to the lack of specificity in the TPC results obtained with spectrophotometric methods, it was decided in this study to also determine the quantities of polyphenols using chromatographic methods.

Table 4: Correlations between TP content and AC assays of dried orange snacks.

Analyses	Correlation coefficient (R^2)			
	CUPRAC	DDPH	FRAP	TP content
CUPRAC	1.000			
DPPH	0.5141	1.000		
FRAP	0.6042	0.5774	1.000	
TP content	0.9359	0.7366	0.6460	1.000

3.8. Phenolic Profile of Orange Snacks. The effect of HTAD and HTAD-MW on the phenolic composition of the orange slices is indicated in Table 5. Totally, 5 phenolic acids, namely, vanillic acid, gallic acid, chlorogenic acid, sinapic acid, and *o*-coumaric acid, and 3 flavonoids, namely, epicatechin, hesperidin, and naringenin were identified with HPLC. Figure 8 shows the respective HPLC chromatogram of the sample dried with 80°C HTAD-MW at 280 and 312 nm.

The result indicated that the major flavonoid and phenolic acid compounds of extracts from fresh and dried orange slices were hesperidin (1370.10–5592.13 mg/g dw) and vanillic acid (49.36–503.63 mg/g dw), respectively. Hesperidin, primarily found in the pulp segments and membranes that separate them in citrus fruit, accounted for about 90% of the flavanone glycosides found in oranges [95]. Hesperidin was described as the most prevalent flavanone glycoside in both mature and immature citrus fruit peels and in navel orange in the literature [96–98]. However, Russell et al. [99] reported the most abundant phenolic compounds in oranges as ferulic acid. Researchers indicate that ferulic acid, one of the hydroxycinnamic acids, has a role in crosslinking wall polymers. Thus, it was emphasized that ferulic acid content was high in orange due to the albedo contacts remaining in the renewable parts of the fruit.

The distribution of the various phenolic contents matched the TP content findings. The level of phenolic components in dried orange snacks was generally found to be significantly lower than in the fresh sample. Long-term heat treatments may cause permanent chemical changes in phenolic compounds, which could explain the degradation of phenolics after drying [100]. Additionally, phenolics can degrade due to other factors such as the activity of oxidative enzymes (polyphenol oxidase, peroxidase), organic acid level, sugar concentration, and pH. These findings agree with the outcomes of Senica et al. [101] who claimed that the heat treatments led to phenolic degradations.

The least and highest degraded phenolics after drying of orange snacks were hesperidin (75.49%) and *o*-coumaric acid (94.78%), respectively. Consistent with TP content results HTAD-MW applied orange snacks exhibited a higher phenolic composition than the HTAD method. For the HTAD-MW method, a drying temperature of 80°C had come to the fore in all drying temperatures based on phenolic content. The reason for this result was explained earlier in the TP content section, with the use of Mpt, drying the orange snacks in a shorter time and thus less exposure to heat [84].

3.9. Principal Component Analysis (PCA). In order to summarize complex information obtained from the analysis of all interested parameters, we further make use of the benefits of PCA. The mean values of gallic acid, vanillic acid, catechin, epicatechin, hesperidin, naringenin, chlorogenic, sinapic, and o-coumaric contents, as well as the mean levels of AA content, TP content, and AC (DPPH radical scavenging, FRAP, and CUPRAC activities) were included in the analysis.

Following a PCA of the experimental results, the analyzed data were divided into two principal components (PCs), namely, PC1 and PC2. PC1 accounted for 89.80%, and PC2 represented 5.97% of the variance; hence, the biplot of the PCA (Figure 9) covered 95.77%, indicating that the PCA is highly representative of all analyzed data and interpretable. PCA was used to identify clusters among the data for the six different drying conditions. The contribution of the first two principal components accounted for 95.77%, with PC1 mainly contributing to AA (0.918), vanillic (0.896), gallic (0.883), o-coumaric (0.876), chlorogenic (0.861), epicatechin (0.859), CUPRAC (0.850), sinapic (0.847), hesperidin (0.794) and naringenin (0.698), while PC2 mainly contributed to DPPH (0.958), FRAP (0.922), and TPC (0.711), respectively. Figure 9 shows that the PC1 scores of HTAD 60°C, HTAD 80°C, and HTAD-MW 80°C were much higher than the scores of the other conditions because the former produced samples with higher contents of ascorbic acid, vanillic, gallic acid, naringenin, and hesperidin. The HTAD 60°C, HTAD 80°C, and HTAD-MW 80°C samples were much more correlated with the fresh samples, which indicated that this treatment had a positive impact on the phenolic compounds. Drying conditions had a rather low concentration for PC2. Moreover, our results for PC1 and PC2 showed that the polyphenolic parameters had a similar direction, indicating a high correlation between them, in agreement with Kittibunchakul et al. [102]. Similarly, previous studies supported the chemical changes in fruit during dehydration, where different drying methods and temperatures were key factors influencing the levels of bioactive compounds in the dried products [102–104].

Table 5: Contents of individual phenolics in orange slices before and after drying (mg/g dw).

Drying conditions	Phenolic acid					Flavanoid		
	Vanillic acid	Gallic acid	Chlorogenic acid	Sinapic acid	o-Coumaric acid	Epicatechin	Hesperidin	Naringenin
Fresh orange slices	503.63 ± 71.16^{a}	181.30 ± 22.00^{a}	187.22 ± 18.98^{a}	254.56 ± 11.52^{a}	169.21 ± 32.00^{a}	930.75 ± 39.44^{a}	5592.13 ± 615.03^{a}	236.86 ± 19.90^{a}
60°C HTAD	100.06 ± 4.54^{b}	28.67 ± 3.86^{b}	26.35 ± 2.72^{c}	45.32 ± 6.43^{cd}	8.83 ± 1.54^{b}	215.91 ± 32.87^{ab}	2783.31 ± 189.29^{b}	88.26 ± 1.39^{de}
70°C HTAD	73.35 ± 13.03^{b}	34.52 ± 2.54^{b}	39.28 ± 4.42^{bc}	59.99 ± 6.61^{b}	22.22 ± 1.45^{b}	226.66 ± 56.25^{ab}	2223.06 ± 138.94^{bc}	145.65 ± 47.75^{bc}
80°C HTAD	88.87 ± 7.89^{b}	33.94 ± 2.98^{b}	35.56 ± 2.14^{bc}	30.66 ± 3.95^{e}	17.98 ± 3.01^{b}	165.94 ± 36.75^{c}	1890.61 ± 58.36^{cd}	73.19 ± 3.53^{de}
60°C HTAD-MW	49.36 ± 7.91^{b}	31.89 ± 1.14^{b}	42.62 ± 0.92^{bc}	54.16 ± 0.55^{bc}	20.53 ± 8.11^{b}	254.14 ± 13.13^{b}	2792.23 ± 144.99^{b}	100.11 ± 3.85^{cd}
70°C HTAD-MW	65.83 ± 14.22^{b}	31.80 ± 1.36^{b}	35.03 ± 7.41^{bc}	60.49 ± 2.41^{b}	13.16 ± 1.38^{b}	154.97 ± 10.76^{c}	1370.10 ± 24.28^{d}	44.64 ± 0.62^{e}
80°C HTAD-MW	106.03 ± 7.59^{b}	40.28 ± 0.98^{b}	48.60 ± 2.59^{b}	38.59 ± 2.11^{de}	8.47 ± 0.78^{b}	224.77 ± 15.91^{bc}	2248.28 ± 17.53^{bc}	157.50 ± 13.27^{b}

Note. Different lower case letters indicate significant differences in the same column ($p < 0.05$).

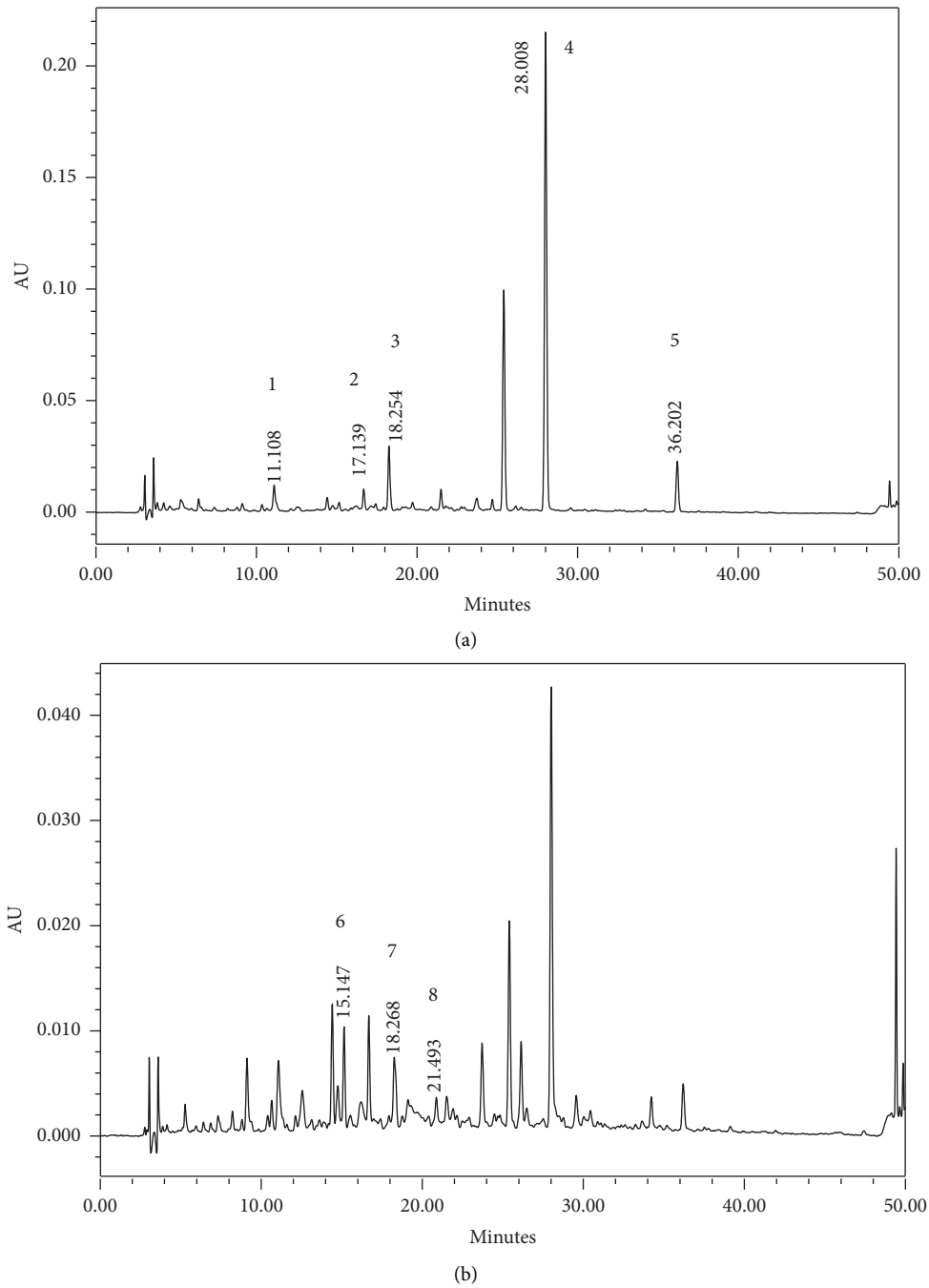

Figure 8: The HPLC chromatogram of the sample dried with 80°C HTAD-MW. (a) 280 nm: (1) vanillic acid; (2) gallic acid; (3) epicatechin; (4) hesperidin; and (5) naringenin; (b) 312 nm: (6) sinapic acid; (7) chlorogenic acid; and (8) o-coumaric acid.

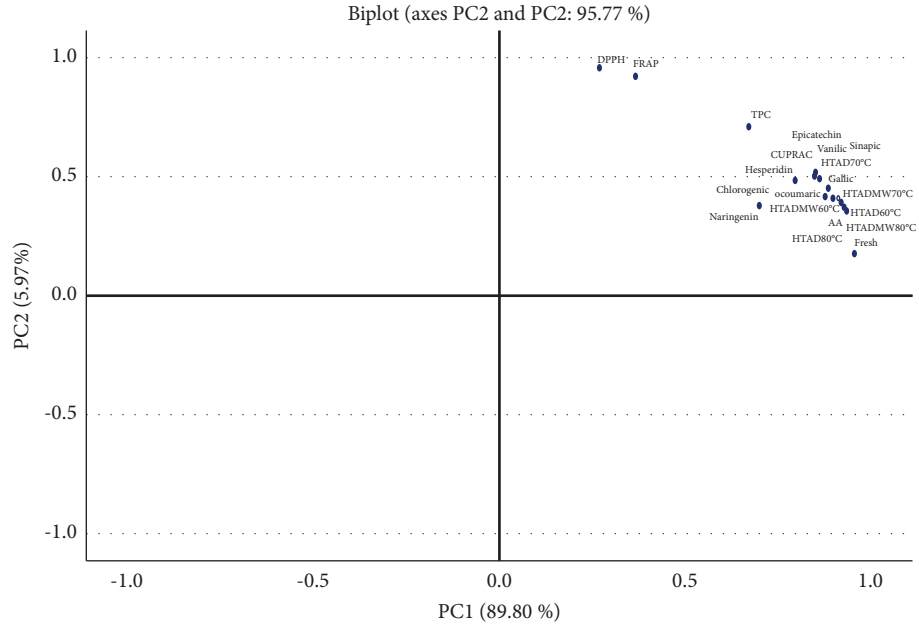

Figure 9: Plot values of PC1 and PC2 according to the phenolic profile, AA content, TP content, and AC in orange snacks.

4. Conclusion

This research revealed the effect of microwave pretreatment prior to HTAD on drying kinetics, rehydration capacity, EMD, total and individual phenolics, AC, AA content, and color of orange snacks. Drying data were well correlated with logarithmic, Wang and Singh, diffusion approach, two term models, and Wang and Sing models which gave the best fit for drying orange snacks. EMD values found between 1.7745×10^{-7} and 5.712×10^{-7} m^2s^{-1}. The rehydration capacity values reached their maximum levels using the HTAD-MW method at a temperature of 70°C. Additionally, the rehydration capacity of dried orange snacks increased as the rehydration temperature rose from 30°C to 60°C. After drying AA, the values for total and individual phenolics and AC values were significantly reduced ($p < 0.05$). The minimum reduction of TP content and AC (DPPH, FRAP, and CUPRAC assays) was achieved using the HTAD-MW application at 60°C. However, in the HTAD-MW method, the AA decrement was greater than with HTAD. In addition, the samples dried with HTAD at 70°C, which had the lowest ΔE^*_{ab} value, showed the properties closest to fresh. Among all drying conditions, HTAD-MW at 80°C enabled best drying and quality properties for dried orange snacks, i.e., short drying time, highest EMD, drying rate, and most retained amount of individual phenolic compounds. As a conclusion, HTAD-MW method may be advised as the most appropriate method for drying orange snacks among tested aspects except AA and color.

Bioaccessibility is defined as the amount of the component released from a food matrix in the gastrointestinal system. Therefore, further studies should be dedicated to *in vitro* bioaccessibility studies to provide insights into the availability of bioactive compounds in the dried orange snacks when consumed, which is vital for understanding their potential health benefits. Moreover, further investigations are needed to specify the sensory attributes, shelf life, and consumer preferences of dried orange snacks which facilitate the product development and market success.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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