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Research Article

Antioxidant Activity and Volatile Composition of Red Araçá Pulp Under Different Drying Conditions

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Araçá fruit extracts were dried at different air conditions, and an investigation of the impact of drying on the volatile composition and antioxidant activity of araçá extracts was conducted. The effective moisture diffusivity varied between 8.542×10^{-8} and 13.34×10^{-8} m^2/min. Fruit extracts dried at 50°C and 2.0 m/s had the highest total antioxidant activity (1916.10 $mg_{ascorbic\ acid}$/100 $g_{araçá}$). The highest phenolic content (556.28 mg_{GAE}/100 $g_{araçá}$) was obtained when fruits were dried at 40°C and 1.5 m/s, but the resulting extract contained high amounts of 5-hydroxymethylfurfural (HMF), a contaminant formed in sugar-rich foods as a result of heating. Araçá extracts had similar qualitative profiles of volatile compounds by GC-MS, with caryophyllene being the most abundant terpene, followed by 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one, selina-3,7(11)-diene, γ-terpinene, γ-cadinene, and α-salinene. HMF corresponded to the major peak in all chromatograms, proving that thermal drying affected the quality of the extracts.

1. Introduction

Psidium cattleianum Sabine belongs to the Myrtaceae family and is commonly referred to as strawberry guava or araçá. This plant is distinguished from the common guava, *P. guajava*, by its more attractive foliage and fruit. Araçá berries, which can be yellow or red, have a nice balance between soluble solids and acidity, and araçá ripens in Brazil in late summer, between February and May [1]. The ripe fruit can be eaten raw or used to prepare juices, wine, and liqueurs. Other studies from the literature have indicated that antioxidant activity, phenolic content, and different carotenes may vary according to the fruit genotypes [2, 3]. Furthermore, knowing the antioxidant activity and bioactive compounds content of different fruit genotypes may aid the valorization of natural products that increase the protection against cellular oxidation or have antimicrobial or anticarcinogenic activities [4]. In the literature, a small number of research papers have analyzed the chemical composition and antioxidant activity of araçá. In these studies, different solvents were employed to obtain the pulp extract, such as diethyl ether [5], acetone/water [6], deionized water and acetone [7], hexane, ethyl acetate, and methanol [8], and ethanol [5]. Then, the antioxidant capacity was measured by using two major methods, the DPPH (2,2-diphenyl-1-picrylhydrazylhydrate) radical photometric method, conducted in the presence of methanol [7, 9], and the Trolox equivalent antioxidant capacity method [6, 8]. The results for the red araçá pulp while varying the extraction method and the method used to determine the antioxidant capacity were 29.29 to 37.69 mg/100 g and 48.05 μg/mL [7, 9] and 1 to 47 and 11.3 μmol Trolox g^{-1} fresh weight [6, 8]. Moreover, in

the literature, the volatile composition of red araçá pulp was analyzed by GC-MS using hydrogen gas at 280°C, resulting mostly in ethanol, α-pinene, (Z)-3-hexenol, (E)-β-caryophyllene, and hexadecanoic acid [5]. In spite of that, in the literature, there is no mention of the influence of drying conditions on these properties. Thermal treatments can affect the quality of the raw material due to the reduction of volatile compounds or the formation of new compounds by oxidation or esterification reactions [10]. Therefore, the effect of drying on the chemical composition of dried fruit extracts is of vital technological and nutritional importance [11]. In view of the above, the present work aimed at mathematically modeling the thin-layer drying of araçá and at evaluating possible alterations of antioxidant activity and volatile composition of red araçá extracts submitted to different convective drying conditions.

2. Materials and Methods

2.1. Sample Preparation. Red araçá (*Psidium cattleianum* Sabine) fruits were collected in the region of Guarapuava (State of Paraná, Brazil). The fruits were harvested ripe (giving preference to the red ones), sanitized (sodium hypochlorite 200 ppm), and cut into slices measuring 0.7 ± 0.15 cm thickness, 1.6 ± 0.21 cm width, and 3.0 ± 0.18 cm length. The slices were stored in plastic bags (polyethylene) of approximately 1 kg, packed in a vacuum-bag, and frozen (−18°C) until the moment of drying. The moisture content (%) of the samples at the beginning and at the end of the drying tests was determined by the gravimetric method: the samples were dried at 105°C until constant weight (difference <0.001 g). The analysis was done in triplicate, and the results were expressed as mean ± standard deviation.

In order to obtain the kinetic data required for the thin-layer convective drying modeling, the samples were dried in a convective drying system. The samples' mass throughout the drying process was weighed on a digital scale at 10 min intervals until equilibrium (i.e., difference between measurements <0.001 g). The effects of air temperature and velocity on the drying kinetics were evaluated according to a complete factorial design, performed in triplicate at the central point (Table 1).

The antioxidant activity was the selected response for each extract obtained according to the experimental design outlined in Table 1.

2.2. Thin-Layer Drying Modeling. The diffusion equation, which represents the mass balance for the araçá slices over drying, was written in Cartesian coordinates as follows:

$$\frac{\partial X}{\partial t} = D_{\text{eff}} \frac{\partial^2 X}{\partial z^2}, \tag{1}$$

where X is the araçá pulp's moisture content on dry basis (d.b.), D_{eff} is the effective mass diffusivity (m^2/min), and z is the spatial coordinate (m).

One initial condition was required to solve the partial differential equation, Equation (1), assuming that the initial moisture distribution in the slices was uniform:

Table 1: Experimental design (coded and real values) used to determine the drying conditions of red araçá fruits.

Run	Temperature (°C)	Air velocity (m/s)
1	−1 (40)	−1 (1.5)
2	+1 (60)	−1 (1.5)
3	−1 (40)	+1 (2.5)
4	+1 (60)	+1 (2.5)
5*	0 (50)	0 (2.0)

*Triplicate runs.

$$\begin{aligned} t &= 0, \\ X &= X_0, \quad 0 \le z \le L, \end{aligned} \tag{2}$$

where X_0 is the slices' initial moisture (d.b.) and L is the slices' thickness (m).

The boundary conditions consist of the Neumann and Dirichlet conditions:

$$\begin{aligned} \left.\frac{\partial X}{\partial z}\right|_{z=L/2} &= 0, \\ X|_{z=L} &= X_{\text{E}}, \quad t > 0, \end{aligned} \tag{3}$$

where X_{E} is the equilibrium moisture content (d.b.).

The governing equation was discretized in relation to space by finite differences, resulting in a system of ordinary differential equations (ODEs). The dsolve routine of Maple 13 software (Waterloo Maple Inc.) was used to solve the ODE system.

The effective mass diffusivity, D_{eff}, was estimated by the nonlinear simplex optimization method, using the NLPSolve command. The estimation was conducted so that the parameter was constant at each drying temperature, that is, independent of the dryer's operation speed. The resulting minimized equation was

$$\text{OBJ} = \sum_{i=1}^{N_{\text{run}}} \sum_{j=1}^{N_i} \left(\frac{X_{\text{EXP}_{i,j}} - X_{\text{CAL}_{i,j}}}{X_{\text{EXP}_{i,j}}} \right)^2, \tag{4}$$

where OBJ is the objective function, N_{run} is the number of experimental data, X_{EXP} is the experimental average moisture content of the fruit (d.b.), and X_{CAL} is the calculated average moisture content of the fruit (d.b.).

2.3. Extraction of Bioactive Compounds. Red araçá samples dried under different conditions were subjected to ethanol extraction according to the methodology described by Ribeiro et al. [12], with some adaptations. Approximately 4.0 g of dried red araçá were weighed, and absolute ethanol was added at a 1 : 10 (w/v) mass : solvent ratio. The extraction was performed in a shaker at 120 rpm for 4 h at room temperature (25°C) and protected from light. The mixture was filtered (11 μm), and the solvent was evaporated under reduced pressure at 40°C. The concentrated material was solubilized in 4 mL of ethanol and stored in an amber bottle in a freezer (−18°C) until the determination of antioxidant activity was completed.

2.4. Antioxidant Capacity. The antioxidant activity was determined following the procedure described by Mensor et al. [13] using 1,1-diphenyl-2-picrylhydrazyl (DPPH) as reagent. Starting from the stock solution (100 μL/mL) of ethanolic extract, solutions with final concentrations ranging from 5 to 25 μL/mL were prepared. Aliquots of 2.5 mL of each extract solution were transferred to test tubes protected from light, and 1 mL of a recently prepared DPPH ethanolic solution (0.3 mM) was added into each tube. The solutions were well mixed and left to react in the dark for 30 min at room temperature. The absorbance ($\text{abs}_{\text{sample}}$) was then measured at 517 nm using a spectrophotometer (Bel Photonics, 2000UV). The blank was prepared by mixing 1 mL ethanol with 2.5 mL extract, and the negative control was prepared by mixing 1 mL of DPPH solution and 2.5 mL of ethanol. The absorbance of these solutions was also measured ($\text{abs}_{\text{blank}}$ and $\text{abs}_{\text{control}}$). The spectrophotometer was zeroed with ethanol (99.5%), and ascorbic acid was used as the positive control (standard). The results were obtained in triplicate, and the antioxidatant activity (AA) was calculated from the following equation:

$$\text{AA}(\%) = \left\{ \frac{\left[\text{abs}_{\text{control}}\left(\text{abs}_{\text{sample}} - \text{abs}_{\text{blank}}\right)\right]}{\text{abs}_{\text{control}}} \right\} \times 100. \quad (5)$$

This activity was expressed as the half-maximum inhibitory concentration (IC_{50}), which was defined as the concentration (μg/mL) of extract required to inhibit the production of radicals by 50%.

The total antioxidant content was determined by the spectrophotometric method involving phosphomolybdenum reductions as described by Prieto et al. [14]. The method is based on the reduction of Mo^{+6} to Mo^{+5} with subsequent formation of a phosphate-Mo^{+5} complex, which presents maximum absorption at 695 nm. A 0.04 mL aliquot of the extracts (0.1 g/mL) was combined with 3.0 mL of reagent solution (0.6 M sulfuric acid, 28 mM sodium phosphate, and 4 mM ammonium molybdate). The samples were incubated at 368.15 K for 90 min. After the samples were cooled to room temperature, they were centrifuged and the solution's absorbance was measured at 695 nm against a blank (3.0 mL reagent solution and 0.04 mL ethanol). The results were expressed as $\text{mg}_{\text{ascorbic acid}}/100\ \text{g}_{\text{araçá}}$ (dry weight).

The total phenolic content (TPC) was determined by the Folin–Ciocalteau method as described by Singleton and Rossi [15]. The total phenolic assay was performed as a measure of the reducing capacity of the sample. The reaction mixture, composed of 0.1 mL of extracts (0.1 g/mL), 7.9 mL of distilled water, 0.5 mL of Folin–Ciocalteau reagent (a mixture of phosphomolybdate and phosphotungstate), and 1.5 mL of 20% (m/v) sodium carbonate, was poured into opaque flasks. The flasks were shaken and left to stand for 2 h, and the absorbance was measured at 765 nm. The TPC was calculated according to a standard curve previously prepared with gallic acid as standard. The results were expressed as milligrams of gallic acid equivalent (GAE) per 100 g of araçá (dry weight) (mg GAE/100 g of araçá).

2.5. GC-MS Analyses. All extracts were analyzed by GC-MS (Agilent 7890A and Agilent 5975C). A nonpolar capillary column HP-5MS (30 m × 0.25 mm i.d., 0.25 μm film thickness, 5% phenyl/95% dimethylpolysiloxane) was used. Helium was the carrier gas, and the injection volume was 1.0 μL. For the column, an initial temperature of 50°C was maintained for 1 min and was then increased at a rate of 2°C/min until 200°C, which was maintained for 1 min. Source and quadrupole temperatures were 230°C and 150°C, respectively. The mass spectrometer was programmed to scan from 40.0 to 1000.0 m/z. The compounds were tentatively identified based on the database of the NIST-11 library by comparing their retention indexes (RIs) to a homologous series of n-alkanes (C8–C40) and through comparison with MS data presented in the literature. The other data processing approach used was the AMDIS (Automated Mass Spectral Deconvolution and Identification System) software. Linear retention indexes were calculated according to the following equation:

$$\text{RI}_x = 100y + 100(z - y)\frac{t_{(r)x} - t_{(r)y}}{t_{(r)z} - t_{(r)y}}, \quad (6)$$

where y is the carbon number of the standard alkane to the left of the peak under evaluation, z is the carbon number of the standard alkane to the right of the peak under evaluation, $t_{(r)x}$ is the retention time (min) of the peak under evaluation, $t_{(r)y}$ is the retention time of the standard alkane on the left, and $t_{(r)z}$ is the retention time of the standard alkane on the right.

2.6. Statistical Analysis. The results were statistically analyzed using the software Statistica 7.0 (Analytical Software, Tallahassee, FL, USA), and each response was evaluated independently. p Values less than 0.05 ($p < 0.05$) were considered statistically significant. Principal components analysis (PCA) was undertaken to compare the extracts obtained at different drying conditions and to verify the relationship among samples and their volatile compounds, total phenolic content, and antioxidant properties.

3. Results and Discussion

3.1. Thin-Layer Drying Modeling. The effective mass diffusivity was estimated simultaneously with the numerical resolution of the mathematical model. The initial moisture content of the fresh araçá used in the model as the initial condition was 79.54% ± 0.54% (d.b.).

The estimated effective mass diffusivity, D_{eff}, for each drying condition is listed in Table 2.

Based on the results from Table 2, an Arrhenius-type dependence was observed between the drying temperature and the effective mass diffusivity of the red araçá fruit. D_{eff} ranged from 8.542×10^{-8} to 13.34×10^{-8} m^2/min, in accordance with the values found in the literature for other fruits, such as pineapple [16], banana [11], and fig [17]. Figure 1 shows the experimental and simulated drying kinetics for all three drying temperatures (40, 50, and 60°C).

Table 2: Effective mass diffusivity estimated for red araçá fruits.

$T_{G_{feed}}$ (°C)	D_{eff} (m^2/min)
40	8.542×10^{-8}
50	9.585×10^{-8}
60	13.44×10^{-8}

According to Figure 1, the higher the drying temperature, the shorter the time required to reach the moisture equilibrium between the araçá fruits and the drying air. However, air velocity did not impact on the drying time as occurred with air temperature since the material does not exhibit a constant drying rate.

Even though the increase of drying air velocity provides higher mass transfer convective coefficients, the increase of air velocity from 1.5 to 2.5 m/s did not promote acceleration of the drying rate. This indicates that air velocities around 1.5 m/s were sufficient to guarantee a low resistance to mass transfer on the surface of the araçá's slices. Accordingly, air velocities around 1.5 m/s should be used to reduce the energy demand of the process in the range of velocities studied.

The coefficients of determination indicated that more than 97% of the mean moisture variation of the araçá slices was explained by the proposed model, under the conditions studied. The final product had a moisture content of 13.58% ± 0.40% (d.b.).

3.2. Antioxidant Capacity. The extracts obtained from the dried araçá samples were evaluated for antioxidant activity by the DPPH method, total antioxidant content by the phosphomolybdenum reducing method, and total phenolic compound content. The results are expressed as mean ± standard deviation (Table 3).

Figures 2–4 show the effects of air temperature and velocity on the IC_{50}, antioxidant activity and total phenolic compounds of the extracts, respectively.

According to the IC_{50} results (Table 3), the sample dried at 50°C and 2.0 m/s (central point of the factorial design) yielded the highest antioxidant activity (1265.21 $\mu g_{araçá}$/mL). The IC_{50} results were positively affected by the drying temperature and negatively affected by the air velocity. It is worth noting that low IC_{50} values are desired since they indicate higher antioxidant activity (Figure 2).

The best drying condition combines mild air temperatures and velocities. Denardin et al. [9] evaluated ethanolic extracts obtained from red araçá and found an IC_{50} of 48.05 μg/mL. In our study, IC_{50} was calculated based on the amount of dried fruit used in the extraction rather than on the quantity of extract, as was done in other studies, so higher IC_{50} values were expected.

The total antioxidant activity (TAA) obtained for the extracts ranged from 1165.42 to 1916.10 $mg_{ascorbic\ acid}/100\ g_{araçá}$. Both air temperature and air velocity had a significant effect on the TAA, as had the interaction between these variables ($p < 0.05$) (Figure 3).

By lowering the drying temperature and increasing the air velocity, it was possible to maximize the antioxidant activity within the studied range of process conditions. These results confirm that temperature reduces the TAA of fruits due to either the destruction of phenolic compounds [18] or by structural changes. Higher air velocities may increase the mass transfer rates, causing less damage to the compounds responsible for the antioxidant activity [19].

The combination of the studied variables was also significant, and the highest TAA (1916.10 $mg_{ascorbic\ acid}/100\ g_{araçá}$) was obtained at the central point condition, 50°C and 2.0 m/s. This TAA is much higher than the value found by Medina et al. [7], 24 mg/100 g for red araçá and 7.2 mg/100 g for yellow araçá.

The ethanolic extracts obtained from the dried samples yielded TPCs from 347.23 to 556.28 $mg_{GAE}/100\ g_{araçá}$, which classify them as extracts of medium and high TPC [20]. The highest amount of phenolic compounds was found for the extracts dried at 40°C and 1.5 m/s (556.28 $mg_{GAE}/100\ g_{araçá}$) and at 50°C and 2.0 m/s (542.68 $mg_{GAE}/100\ g_{araçá}$). The air velocity and drying temperature alone had no significant effect on the TPC ($p < 0.05$), but the interaction between these variables had a positive and significant effect (Figure 4).

Except for run 4 (60°C and 2.5 m/s), the increase in drying temperature and air velocity was followed by a decrease in TPC. This behavior is related to the sensitivity of these metabolites to temperature and to the start of degradation in the presence of oxygen.

The results of TPC found in this work were similar to those from Luximon-Ramma et al. [6], 563 $mg_{GAE}/100$ g. Although the fruits used in both studies were from the same species, the difference in phenolic composition is not surprising as the extraction protocol and the identification methods were different. The TPCs determined in this work using ethanol as extraction solvent for the araçá fruits were close to the values found by Medina et al. [7], 581.02 to 768.21 $mg_{GAE}/100\ g_{fresh\ fruit}$.

Neri-Numa et al. [21] evaluated the TPC of araçá-boi and found mean values of 184.05 $mg_{GAE}/100$ g in ethanol extracts, quite below the lowest value found in this study. The IC_{50} found by the same authors was 0.69 μg/mL, also significantly lower than our results. In our study, a strong correlation was found between IC_{50} and TPC (Pearson correlation coefficient = 0.86).

The influence of the solvent on the extraction of phenolic compounds and consequently the bioactivity of the extracts was demonstrated in some studies [22, 23]. According to the literature, various solvents are often used for antioxidant activity investigation, such as methanol, ethanol, water, and acetone. Water has a disadvantage over ethanol as it requires a freeze-drying step following extraction, while the use of methanol and acetone is limited due to toxicity issues [24].

A combination of methods will describe the antioxidant properties of the product in further detail. Nevertheless, it should be noted that the comparison between results from different studies is somewhat complex since the characteristics of the fruits tested are different, as well as the conditions of cultivation and preparation.

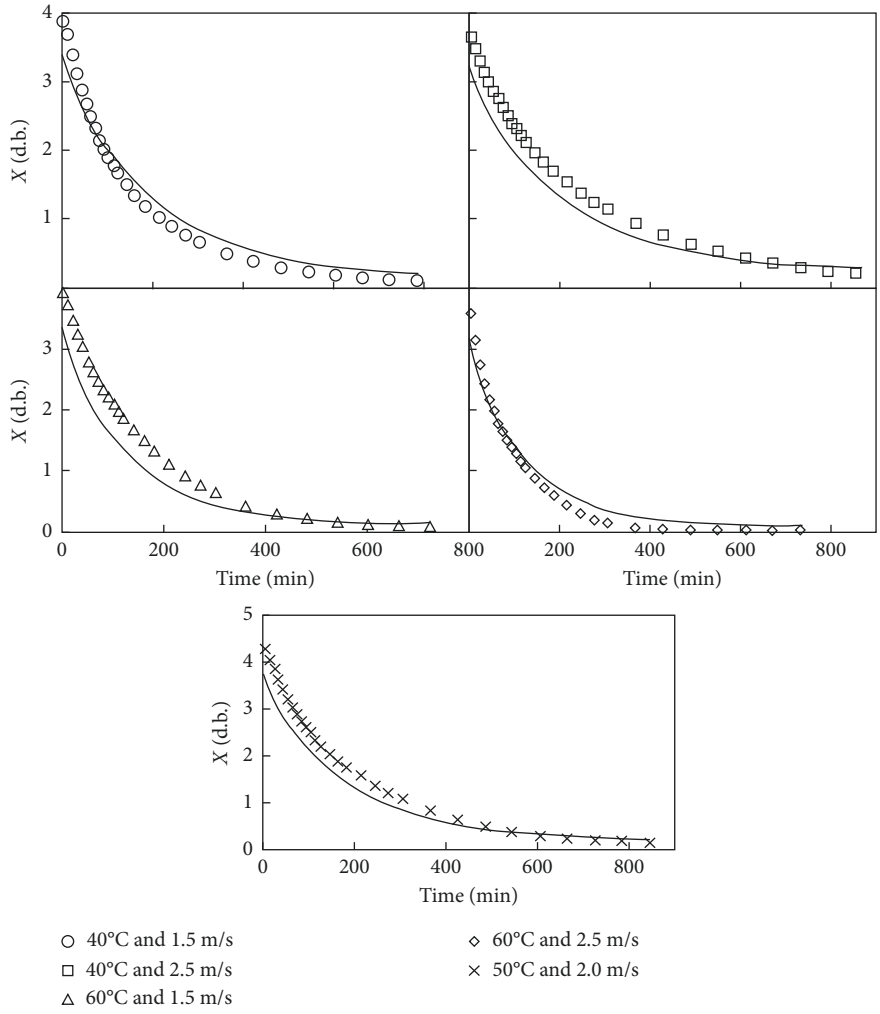

Figure 1: Drying kinetics of red araçá fruits.

Table 3: Antioxidant capacity of extracts obtained from araçá dried under different conditions.

Run	Drying conditions	TPC ($mg_{GAE}/100\,g_{araçá}$)[a]	IC_{50} ($\mu g_{araçá}/mL$)[a]	AAT ($mg_{ascorbic\ acid}/100\,g_{araçá}$)[a]
1	40°C/1.5 m/s	556.28 ± 1.71	1554.36 ± 17.39	1563.88 ± 61.99
2	60°C/1.5 m/s	347.23 ± 1.28	1945.94 ± 18.15	1165.42 ± 39.53
3	40°C/2.5 m/s	392.84 ± 3.57	1688.02 ± 11.28	1829.47 ± 16.10
4	60°C/2.5 m/s	524.09 ± 0.84	1490.79 ± 1.97	1752.81 ± 2.61
5	50°C/2.0 m/s	542.68 ± 4.35	1265.21 ± 3.24	1916.10 ± 0.05

TPC: total phenolic assay by the Folin–Ciocalteu method; IC_{50}: inhibitory concentration defined as the concentration of extract required to inhibit the production of DPPH radicals by 50%; AAT: total antioxidant activity by the phosphomolybdenum reducing method. [a]Average value and standard deviation of triplicate runs.

The highest antioxidant activity and phenolic compound content were obtained at 50°C and 2.0 m/s, which were then selected as the optimal drying condition.

3.3. GC-MS Analyses. The GC-MS analysis of the ethanolic extracts of red araçá fruits (Table 4) showed the existence of various compounds with different chemical structures (terpene, alcohol, ester, ketones, and aldehyde classes).

According to Strehmel et al. [25], the limits of comparison for IR vary according to the complexity of the matrices analyzed, and variations of up to 30 units are accepted for biological matrices. Compounds with highest abundance were found in all extracts, but their relative amount varied. Overall, the major compounds were caryophyllene (9.85–7.49%), 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one (pyranone) (7.23–2.07%), selina-3,7(11)-diene (4.14–1.98%), γ-terpinene (3.10–0.06%),

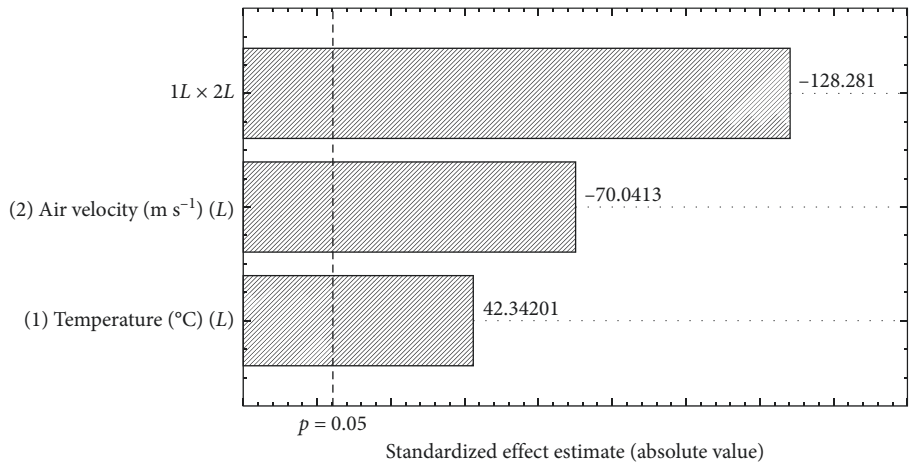

Figure 2: Pareto chart showing the effect of air temperature and velocity on the IC_{50} of the extracts.

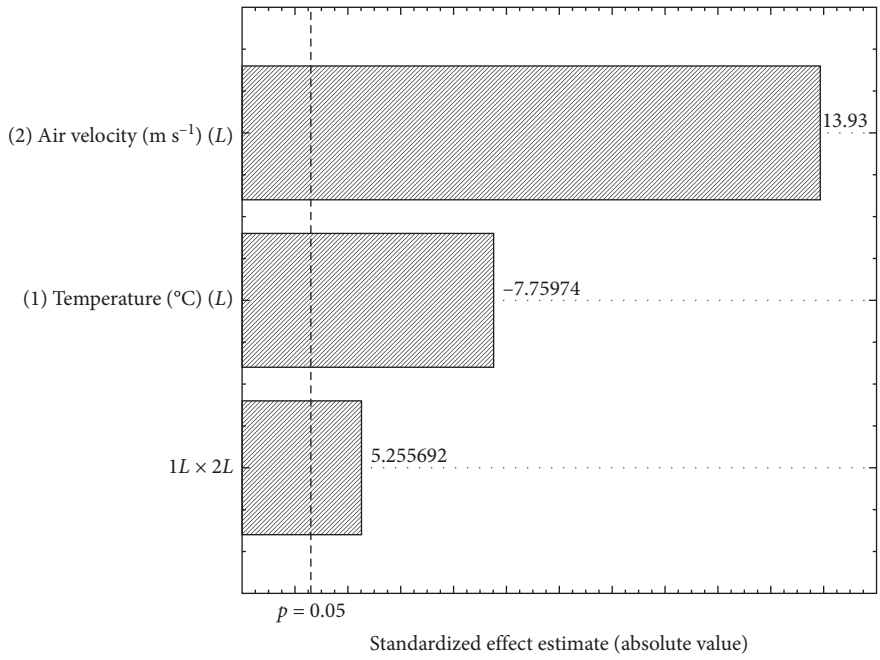

Figure 3: Pareto chart showing the effect of air temperature and velocity on the antioxidant activity of the extracts.

γ-cadinene (2.34–1.78%), and α-salinene (2.53–1.86%). The relative concentration of these compounds did not exhibit any trend when the drying temperature or the air velocity was varied ($p > 0.05$).

Furfural and HMF contents were significantly ($p < 0.05$) affected by both drying temperature and air velocity. The drying temperature and the interaction between the variables had a negative effect on these responses, while air velocity had a positive effect.

Red araçá fruit extracts contain a high number of active compounds (Table 4). The compound 2,3-dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one (DDMP) is a well-known sugar degradation product, arising from 1-deoxy-d-erythro-hexo-2,3-diulose under neutral pH conditions, that exists in various thermally processed foods such as heated vegetables, meat, caramel sweets, and bread crust [26].

Other sugar derivative compounds in red araçá fruit extracts are 5-hydroxymethylfurfural (HMF) and furfural, which are formed as a response to extended periods of storage or severe heat treatment. According to Chambel et al. [27], temperatures ≥50°C cause HMF degeneration, which may explain the fact that run 2 (60°C and 1.5 m/s), run 4 (60°C and 2.5 m/s), and run 5 (50°C and 2.0 m/s) presented lower HMF concentration than run 3 (40°C and 2.5 m/s) and run 1 (40°C and 1.5 m/s). As these unwanted compounds may threaten human health due to their presumably carcinogenic effects [28], it is recommendable to dry araçá fruits

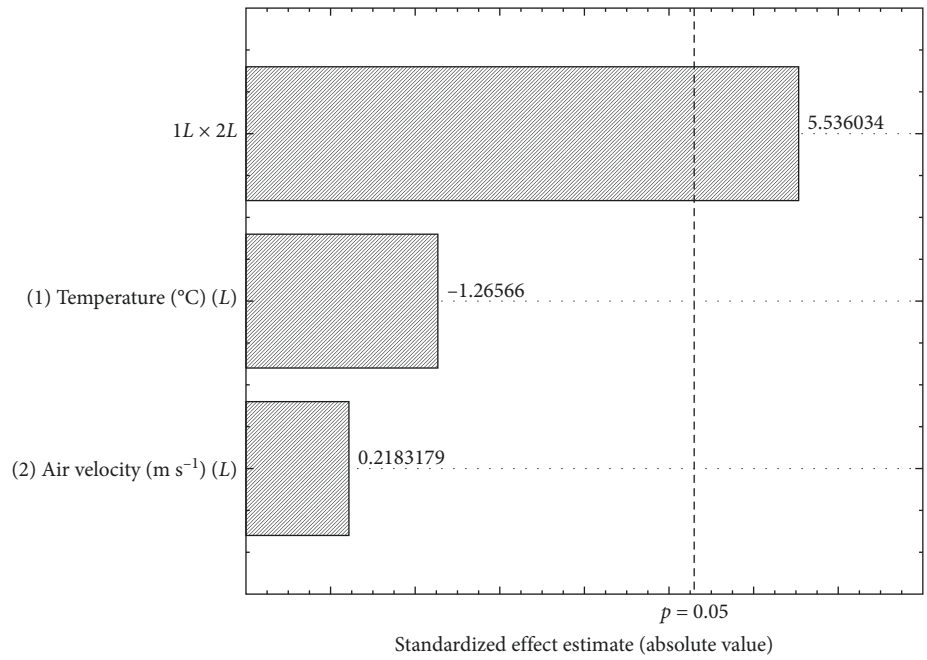

Figure 4: Pareto chart showing the effect of air temperature and velocity on the total phenolic compounds of the extracts.

Table 4: Chemical composition (%) of the volatile fraction of ethanolic extracts of red araçá fruits obtained at different drying conditions.

Compound	t_r (min)	RI[a]	RI[b]	Relative area (%)				
				Run 1 (40°C, 1.5 m/s)	Run 2 (60°C, 1.5 m/s)	Run 3 (40°C, 2.5 m/s)	Run 4 (60°C, 2.5 m/s)	Run 5[c] (50°C, 2.0 m/s)
Furfural (FF)	4.88	—	830	1.98	2.72	6.9	2.5	2.92 ± 0.32
1R-*α*-Pinene	6.81	—	937	nd	nd	0.55	nd	nd
1,1-Diethoxy-3-methylbutane	7.60	—	930	nd	1.42	1.08	0.75	0.77 ± 0.14
β-Pinene	8.43	—	980	nd	nd	0.21	nd	nd
α-Terpinene	9.27	1016	1018	1.00	nd	0.36	nd	nd
δ-Limonene	9.76	1029	1031	nd	2.14	nd	1.40	0.80 ± 0.11
Eucalyptol	9.84	1037	1033	1.79	2.13	1.60	2.00	1.72 ± 0.35
trans-*β*-Ocimene	10.02	1039	1050	0.60	0.81	nd	0.81	0.55 ± 0.16
γ-Terpinene	10.80	1063	1062	0.06	2.50	1.72	3.10	2.29 ± 0.54
Terpinolene	11.64	1088	1088	1.15	1.96	1.83	1.22	0.45 ± 0.12
Linalol	12.09	1099	1098	1.26	1.29	1.24	1.25	1.43 ± 0.46
2,3-Dihydro-3,5-dihydroxy-6-methyl-4H-pyran-4-one ((DDMP)	13.53	1144	1134	2.26	3.40	7.23	2.07	3.28 ± 0.30
Butanoicacidhexylester	15.20	1192	1191	0.75	0.93	0.96	0.80	0.78 ± 0.02
Dodecane	15.43	1199	1200	0.62	1.17	0.97	0.65	0.85 ± 0.08
5-Hydroxymethylfurfural (HMF)	16.34	1226	1224	30.33	12.85	39.56	14.65	23.15 ± 1.33
α-Copaene	21.35	1378	1376	1.60	nd	1.15	1.42	1.24 ± 0.24
Caryophyllene	23.01	1431	1428	9.85	9.16	7.57	8.69	7.49 ± 0.55
Humulene	23.82	1457	1440	0.89	0.77	0.64	0.81	0.68 ± 0.10
γ-Muurolene	24.56	1482	1477	2.00	2.07	1.48	1.88	1.55 ± 0.26
β-Selinene	24.91	1493	1485	2.31	2.12	1.52	2.04	1.74 ± 0.28
α-Selinene	25.20	1502	1494	2.53	2.45	2.07	2.20	1.86 ± 0.15
β-Bisabolene	25.77	1522	1509	1.43	1.21	1.50	1.13	1.02 ± 0.08
γ-Cadinene	26.12	1534	1513	2.34	2.00	2.00	2.09	1.98 ± 0.22
Selina-3,7(11)-diene	26.54	1548	1534	4.14	2.00	2.00	2.96	2.29 ± 0.54
E-Nerolidol	27.19	1571	1564	1.65	0.95	0.77	1.14	0.93 ± 0.09
Cubenol	28.94	1632	1642	1.36	0.73	0.87	0.76	0.74 ± 0.11
γ-Eudesmol	29.06	1637	1629	1.13	0.51	0.37	0.46	0.78 ± 0.21

Table 4: Continued.

Compound	t_r (min)	RI[a]	RI[b]	Relative area (%) Run 1 (40°C, 1.5 m/s)	Run 2 (60°C, 1.5 m/s)	Run 3 (40°C, 2.5 m/s)	Run 4 (60°C, 2.5 m/s)	Run 5[c] (50°C, 2.0 m/s)
(−) δ-Cadinol	29.59	1656	1636	1.05	1.33	0.70	1.24	1.09 ± 0.28
1,3a-Ethano(1H)inden-4-ol-octahydro-2,2.4.7a-tetramethyl	29.82	1664	1648	0.45	1.34	0.99	0.30	nd
Eudesm-7(11)-en-4-ol	30.82	1700	1700	4.50	1.01	0.68	0.99	0.92 ± 012
Total relative area of identified compounds	—	—	—	79.03	60.97	88.53	59.31	64.31 ± 0.32

t_r: retention time; RI[a]: calculated retention index; RI[b]: retention index from Pherobase and Leffingwell. [c]Average values of triplicate runs and standard deviation.

at temperatures of 50°C or higher to promote the degradation of HMF.

Some metabolites have already been identified in red araçá extracts by NMR spectroscopy: triolein, β-sitosterol, ursolic acid, oleanolic acid, 2α-hydroxyursolic acid, 2α-hydroxyoleanolic acid, citric acid, and a mixture of citrate esters (1,2,3-propanetricarboxylic acid-2-hydroxy-1-methyl ester and 1,2,3-propanetricarboxylic acid-2-hydroxy-2-methyl ester). Caryophyllene and its epoxide are well-known volatile constituents of red araçá [8]. As red araçá extracts are important sources of these compounds, their ethanolic extracts have a good market potential.

4. Conclusions

Heat and mass transfer equations were used in the modeling and simulation of the thin-layer convective drying process of red araçá slices. The effective mass diffusivity ranged from 8.542×10^{-8} to 13.44×10^{-8} m^2/min. For all simulated drying conditions, the coefficient of determination was greater than 97%. Under the conditions studied, the increase in air velocity did not promote acceleration of the drying rate. Thus, conducting the process at 1.5 m/s is sufficient to guarantee a low resistance to mass transfer on the surface of araçá slices and reduce the energy demand of the process.

Fruits dried at 50°C and 2.0 m/s had the highest antioxidant activity as determined by the DPPH method ($IC_{50} = 1265.21$ $\mu g_{araçá}$/mL) and the highest TAA (1916.10 $mg_{ascorbic\ acid}$/100 $g_{araçá}$) as measured by the phosphomolybdenum reduction method. Extracts from fruits dried at 40°C and 1.5 m/s had the highest phenolic content (556.28 mg_{GAE}/100 $g_{araçá}$), which was very close to the value (542.68 mg_{GAE}/100 $g_{araçá}$) determined for mild drying conditions (50°C and 2.0 m/s). Although araçá fruit extracts obtained under different drying conditions presented similar chemical composition, the combination of low temperature with high air velocity seemed to increase the contents of HMF and furfural. The most abundant substances found under these conditions were caryophyllene, 2,3-dihydro-3.5-dihydroxy-6-methyl-4H-pyran-4-one (pyranone), selina-3,7(11)-diene, γ-terpinene, γ-cadinene, and β-salinene. Therefore, drying at 50°C and 2.0 m/s is the best condition (within the range studied) for the maintenance of phenolic compounds and other compounds with antioxidant activity in araçá extracts.

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 have declared no conflicts of interest.

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