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ORIGINAL ARTICLE

Uvaia fruit (*Eugenia pyriformis* Cambess) drying: Ethanol as pre-treatment, convective drying kinetics and bioactive compounds

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Abstract

This study evaluated the effects of ethanol pre-treatment on convective drying and its impacts on the bioactive compounds of uvaia. The treatments consisting of control and samples pre-treated by immersion in ethanol (99.8% v/v) for 10 and 20 min, followed by convective drying (1 m/s) at 40 and 60°C. The sample temperatures were traced over processing and the products were evaluated in relation to their content of phenolic compounds and antioxidant capacity. Pre-treatment times in combination with temperatures influenced drying time and were associated with ethanol penetration and volatility in the sample. Furthermore, the high vapor pressure of ethanol reduced the initial temperature of the samples. Drying temperatures and pre-treatments reduced by 16%–34% phenolics compounds and 13%–45% antioxidant capacity, which was associated with degradation and possible extraction by ethanol. The advantages of using ethanol were discussed, but also some limitations, especially on bioactive compounds.

Practical applications

Uvaia is a native fruit rich in sensory and healthy aspects. However, its high perishability and seasonality make it unfeasible for post-harvest commercialization. This work demonstrated that drying and application of ethanol proved to be effective for preserving this fruit, resulting in a shorter processing time. Although ethanol partially extracted the bioactive compounds, significant levels are still found in the final product—which can be used as convenient products with a positive impact on consumers' health. Furthermore, the proposed approach is simple, relatively cheap, and viable techniques to obtain stable products for both industry and small producers.

1 | INTRODUCTION

Brazil has a rich biodiversity with a high potential for commercialization and application in different segments of the industry. However, part of the native fruits is little known and explored due to their seasonal distribution and perishability, which are factors that restrict the commercialization and consumption "*in natura*".

An example is uvaia (*Eugenia pyriformes* Cambess.), a native fruit of the Brazilian Atlantic Forest. This fruit has globe-shaped, thin skin, velvety texture with a striking yellow-orange color. Its pulp is succulent, fleshy, soft, with an exotic flavor, and very aromatic (Jacomino et al., 2018). Furthermore, it has been reported that this fruit can be an interesting source of nutrients due to the presence of carbohydrates (fructose, glucose, and sucrose), proteins, lipids, fibers,

minerals (K, P, Mg, S, and Zn), and antioxidants bioactive compounds such as phenolic compounds, carotenoids and ascorbic acid (da Silva et al., 2019; Farias et al., 2020; Haminiuk et al., 2011; Pereira et al., 2012; Ramirez et al., 2012; Sganzerla et al., 2019).

These sensory and nutritional characteristics are highly appreciated in the fruit. However, uvaia is highly perishable and results in a rapid loss of post-harvest quality, which is a limiting factor for its commercialization (Jacomino et al., 2018). Therefore, alternatives for processing and preservation of this fruit can increase their commercial potential and consumption.

Drying can be an approach to stabilize uvaia, avoiding food losses and expanding its commercialization in different products—the obtained dried uvaia can be directly consumed or used in the elaboration of various food products with natural claim, such as cereal bars, breakfast cereals, granola, cookies, among others. It should be noted that convective drying is a simple and inexpensive method of obtaining stable and safe food (Mujumdar, 2020). Consequently, drying is feasible even to small producers.

However, conventional convective drying with hot air requires a long processing time and results in modifications with impairing the retention of nutrients and compromising the quality of the product (Halder & Datta, 2012). To overcome this challenge, some emerging technologies are being applied to improve the drying process and products, such as the drying accelerators (Carvalho et al., 2020).

Ethanol has been studied as a pre-treatment to convective drying in different fruits and vegetables (Llavata et al., 2020). This emerging technology is simple, effective, and viable techniques for application, but each food matrix has its particularities (Bitencourt et al., 2021; Carvalho et al., 2020). Therefore, studies with different foods, drying conditions, and pre-treatments are still needed to better understand these process combinations and their implications for drying kinetics and product quality.

Therefore, this work proposed and evaluated for the first time the convective drying of uvaia fruit, also studying the pre-treatment with ethanol and their effects on the drying kinetics and bioactive compounds.

2 | MATERIAL AND METHODS

Figure 1 represents the experiment design, including the sample preparation, pre-treatments, performed process and evaluation—which are detailed as follows.

2.1 | Sample preparation and treatments

The uvaia fruits (*Eugenia pyriformis*) were obtained directly from the producer "Sítio do Bello" (Paraibuna, São Paulo, Brazil) in October 2020. The fruits were selected according to their integrity and homogeneity and kept under refrigeration at a temperature of 6°C until processing (up to ~38h).

The fruits were cut into two or four parts (approximately 2 × 2 cm), according to the size of each fruit, also removing manually the seed, in order to standardize the samples during drying. Six treatments were processed: control (without any pre-treatment) and pre-treated with ethanol (two conditions), and then subsequent convectively drying (two temperatures).

Pre-treatments were conducted by immersing the fruit pieces in ethanol (99.8% v/v) at 30°C, for 10 or 20 min, using a ratio of 1:5 (sample mass:volume of ethanol). After immersion, the ethanol was drained, and the samples were superficially dried with absorbent paper to remove the excess ethanol.

Therefore, the six treatments consisted of control samples (C; without any pre-treatment) and pre-treated samples with ethanol for 10 or 20 min (E10 or E20), dried at 40°C or 60°C, whose codes are described in Table 1.

2.2 | Convective drying

The convective drying process was performed in an oven with circulation and air renewal at 1 m/s (Marconi, MA 0.35, Brazil) using two working temperatures: 40°C and 60°C. The temperatures and conditions studied were selected in order to better evaluate the effect of pre-treatment on drying and bioactive compounds as a quality parameter (Figure 1).

The samples were placed on stainless steel grids to allow a better contact area and hot air circulation over all the samples surfaces. The samples were dried until they registered constant weight, which was defined when the mass variation was less than 1%. The samples were weighed every 30 min until completing 120 min of the process and, subsequently, weighed every 60 min until the end of the process. The initial and final moistures ("*in natura*", after pre-treatment and after drying) were measured by completely drying the fruit at 105°C using a moisture analyzer (MX-50, A&D Company, Tokyo, Japan) (Rojas et al., 2019).

During each sampling time over drying, thermographs were obtained through an infrared camera (Testo, Text 865, Germany; 0.95 emissivity). The recorded images were analyzed using the Software IRSoft 4.5 (Text SE & Co, Germany), in which it was possible to select each sample to obtain the surface temperature behavior over processing.

The moisture in each drying time was obtained through the mass balance, considering the moisture obtained at the end of the process (after drying). It is important to highlight that, during the pre-treatment, the fruits gain ethanol and lose water and solids. Therefore, the sample moisture after pre-treatment includes both existing volatile liquids, that is, the remaining water and the absorbed ethanol (Rojas & Augusto, 2018b; Silva et al., 2012).

The drying kinetics were plotted using dimensionless moisture (*MR*) as a function of drying time (min), calculated according to Equation 1,

$$MR(t) = \frac{Mo}{Mt} \quad (1)$$

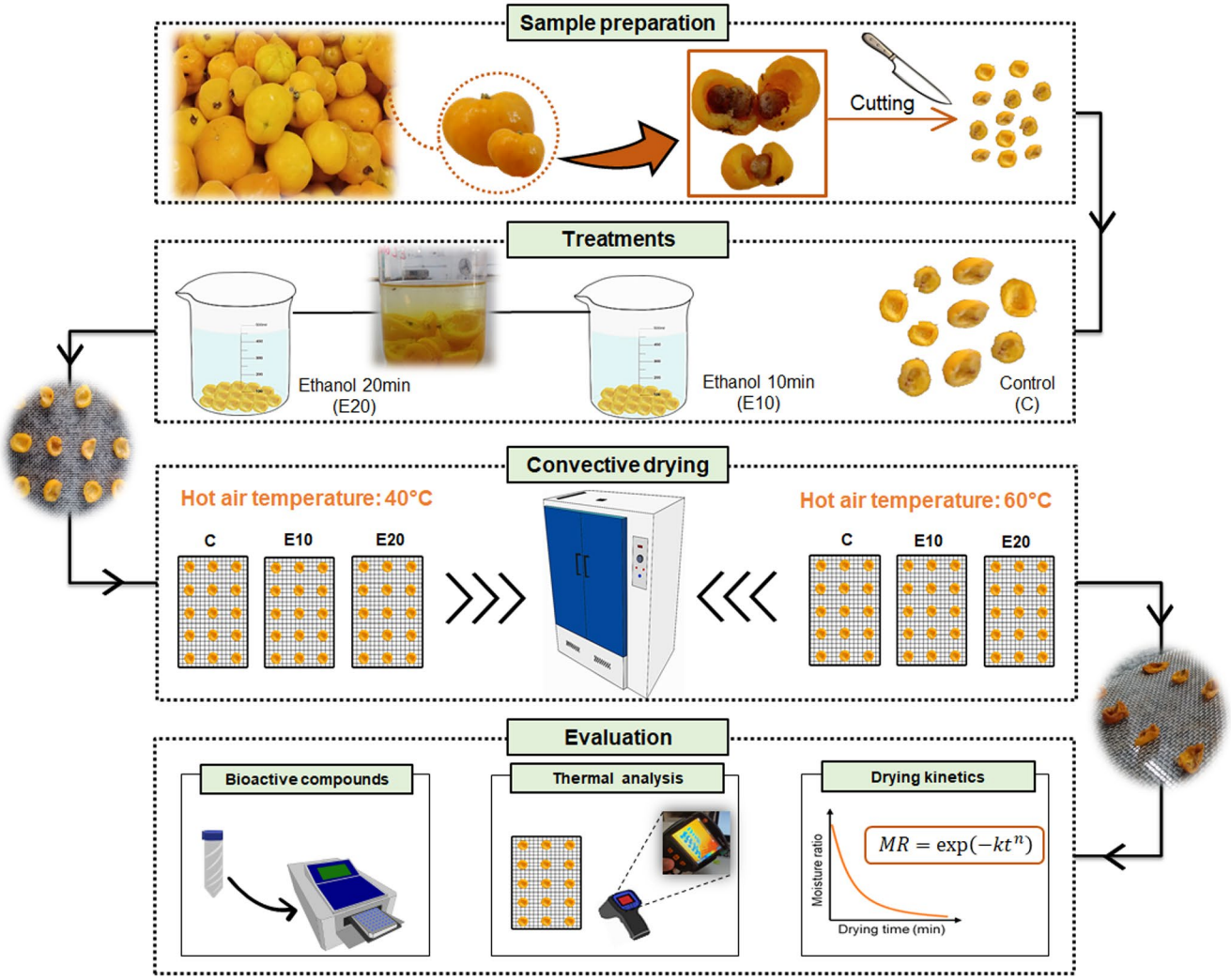

FIGURE 1 Representation of sample preparation, pre-treatments, performed process, and analysis evaluation

TABLE 1 Treatment codes

Pre-treatment	Convective drying	
Time (min)	Temperature (°C)	Treatment code
0		C
10	40	E10
20		E20
0		C
10	60	E10
20		E20

where "*Mo*" corresponds to the initial moisture content (kg_{H2O}/kg d.b.) and "*Mt*" corresponds to the moisture content at each drying time (kg_{H2O}/kg d.b.).

The Page model (Equation 2) (Page, 1949) was used to fit the experimental data, where *MR* (*t*) is obtained by Equation 1, the "*k*" parameter is related to the drying rate (min^{-n}) and the "*n*" is a dimensionless parameter. According to (Simpson et al., 2017), the parameter "*k*" is associated with the diffusion coefficient and geometry of the sample, while the parameter "*n*" describes the type of diffusion ($n = 1$ diffusive; $n > 1$ superdiffusive; or $n < 1$ sub-diffusive). Therefore, it can be useful to discuss the effects of sample microstructure and mass transfer mechanisms. For example, when $n \neq 1$ other mechanisms besides diffusion are important and may be associated, such as capillarity (Rojas & Augusto, 2018b),

$$MR(t) = e^{-k.t^n}. \quad (2)$$

The parameters of the Page model (Equation 2) were adjusted to the experimental data using the generalized reduced gradient algorithm (GRG; nonlinear solution method). The parameters values were valid when GRG found the optimal solution with a set convergence at 0.000001, implemented in the "Solver" tool of the Excel 2020 software (Microsoft, USA). For this, the minimization of the sum of square errors (*SSE*, Equation 3) between the experimental ($M_{experimetal}$) and the predicted data (M_{model}) was used as a criterion. In

addition, the coefficient of determination (R^2) was used to assess the accuracy with which the models fit the experimental data,

$$SSE = \sum_{i=1}^{X} 1\left(\left(M_{model}\right) - \left(M_{experimental}\right)\right)_i^2. \quad (3)$$

2.3 | Evaluating the product quality: bioactive compounds

2.3.1 | Obtaining sample extracts

Ethanolic extracts were obtained from the samples to determine the antioxidant capacity (AC) and total phenolic compounds (TPC) content, according to Farias et al. (2020), Haminiuk et al. (2011) and Rojas, Augusto, et al. (2020), with modifications. For better homogeneity, the dry samples were ground in an analytical mill (A11 Basic, IKA, Brazil) twice for 10 s, with an interval of 1 min between the first and second grinding, thus assuring the temperature did not rise.

The samples were weighed (~ 1 g of "*in natura*" sample and ~0.1 g of dry powder sample, according to the conversion of the equivalent weight for each moisture) in test tubes sealed with aluminum paper for protection from light. Subsequently, the dried samples were rehydrated with distilled water using a ratio 1:9 (dry sample:water in mass), (proportion of water equivalent to the mass of water present in the "*in natura*" sample) for 3 hr using a water bath (DUBNOFF MA 095/CFRE, Marconi, Brazil) under agitation (250 rpm) and controlled temperature of 25°C.

Then, 10 ml of ethanol (80% v/v) were added to each tube. The mixture was agitated in Rotor stator homogenizer (Superohm, Brazil) for 20 s and submitted to a water bath (DUBNOFF MA 095/CFRE, Marconi, Brazil) under agitation (250 rpm) at 25°C for extraction. After 30 min of extraction, the samples were centrifugated at 3291 × *g* (Routine 420R, Hettich, USA) for 20 min at a temperature of 20°C. The supernatant was filtered and placed in hermetic flasks, protected from light, and stored under refrigeration (~6°C) for ~30 min until the moment of analysis.

2.3.2 | Antioxidant capacity

The antioxidant capacity was evaluated through the $ABTS^{\cdot+}$ radical as described by (Re et al., 1999), with some modifications. A calibration curve was plotted from the standard 2.5 mM Trolox solution (Sigma-Aldrich, USA) diluted to obtain different concentrations (from 12.5 to 300 μM).

For analysis, the $ABTS^{\cdot+}$ solution was prepared by reacting the 7 mM ABTS solution (2,2′-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid)) (Roche, Germany) with the 140 mM potassium persulfate solution (Dinâmica Ltda., Brazil), which reacted for 16 hr in the absence of light. The $ABTS^{\cdot+}$ solution was diluted in ethanol until absorbance 0.7 ± 0.0025 at 734 nm, and 220 μL of the diluted $ABTS^{\cdot+}$ solution were added in 20 μL of sample (or standard Trolox solution). The mixture reacted for 10 min, being its absorbance at 730 nm read in a microplate reader (Biochrom Asys Expert Plus Microplate Reader, UK). The antioxidant capacity was expressed in μM Trolox/g dry matter.

2.3.3 | Total phenolic content

The determination of total phenolic compounds (TPC) was carried out through colorimetric analysis by reducing the reagent Folin-Ciocalteu according to Singleton et al. (1999), with modifications. A calibration curve was plotted using a standard solution of gallic acid (GA) 0.5 g/L (Vetec Química Ltda., Brazil). The reaction consisted of homogenizing 100 μL of the sample (or standard solution) with 500 μL of reagent Folin-Ciocalteu 1:10 (v/v) (Sigma-Aldrich, USA) and wait 6 min. Then, 400 μL of sodium carbonate 4% (m/v) (Labsynth Ltda., Brazil) was added and the mixture was left in the dark for 60 min at room temperature for later reading of absorbances at 740 nm using a microplate reader (Biochrom Asys Expert Plus Microplate Reader, UK). The results were expressed in mg equivalent GA (mg GAE/g dry matter).

2.4 | Experimental design and statistical analysis

A completely randomized design (CRD) was conducted. All processes and analyses were performed at least three times. The data were analyzed using the Software Minitab version 18 (Minitab, LLC., USA). The analysis of variance (ANOVA) was applied (significance level of $\alpha = 0.05$) and the averages were compared by the Tukey test using a 95% confidence interval, in order to observe the significant difference between treatments.

3 | RESULTS AND DISCUSSION

3.1 | Convective drying

The drying kinetics, the parameters of Page model (Equation 2), and the processing time are shown in Figures 2 and 3, for the different treatments. The drying time was estimated considering the time necessary to reach final moisture of 20% (wet basis), which corresponds to the minimum moisture necessary to reach microbial stability in dried food products (Chen; Patel, 2008). Moreover, the reduction in drying time was based on the control treatment, as well as each treatment was compared with the control at 40°C for discussion (relative drying time in Figure 3).

Both pre-treatment with ethanol and drying temperature significantly impacted the processing time.

As expected, the temperature had a strong influence on reducing drying time ($p < .05$) (Figure 2). Considering the control treatment, the process at 60°C provided a reduction of ~50% on the drying time when compared to the process at 40°C (Figure 3).

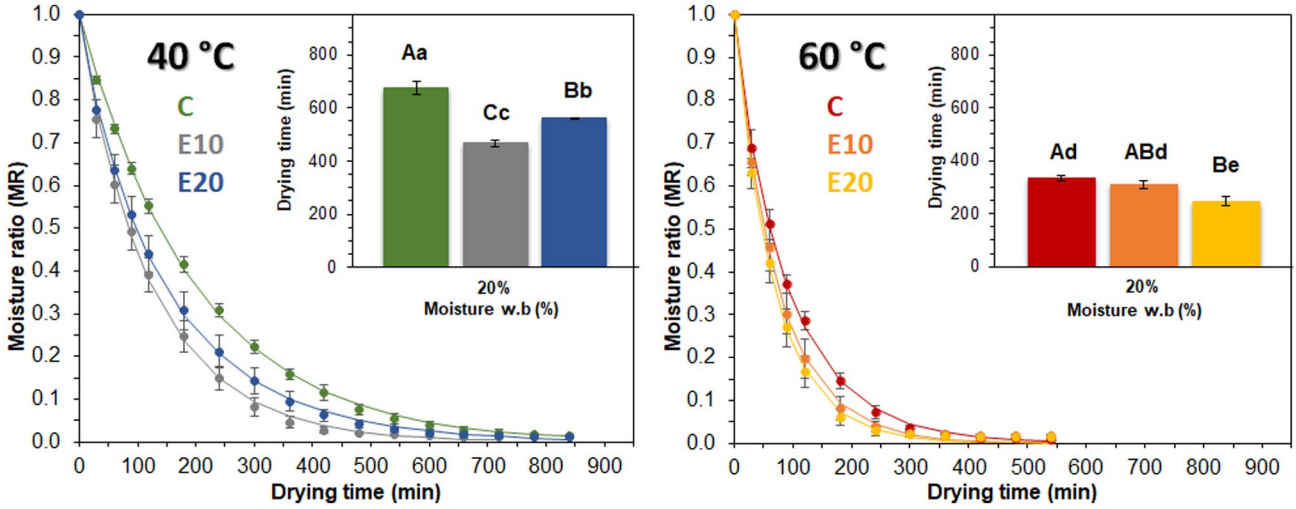

FIGURE 2 Uvaia convective drying behavior at 40°C and 60°C. Dots are the experimental data, whose standard deviation is represented by the vertical bars. The curves are the Page model (Equation 2). The inserted graphics represent the drying time in each treatment and superscript letters indicates Tukey Test (different upper-case letters indicate a significant difference ($p < .05$) within the same temperature, and different lower-case letter indicate a significant difference ($p < .05$) when compared to all treatments). Table 1 shows the treatment codes

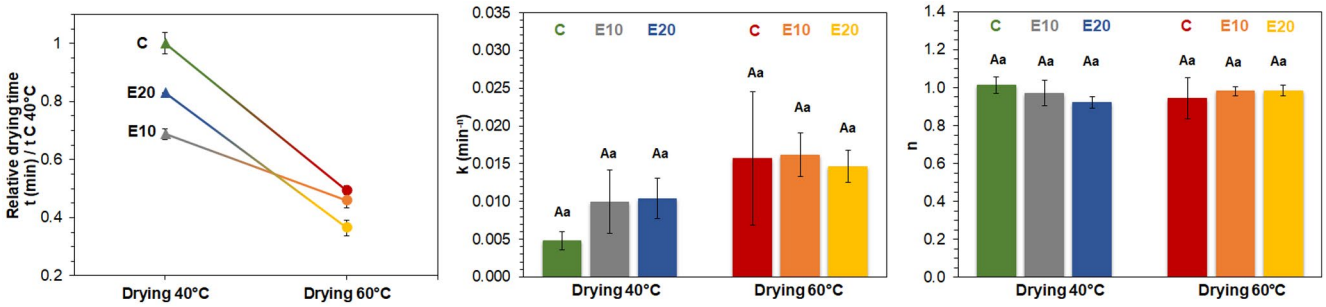

FIGURE 3 Relative drying time and parameters of the Page model (Equation 2), k (min^{-n}) and n, for uvaia drying at 40°C and 60°C. Averages and the standard deviations. The superscript letters indicate Tukey Test: different upper-case letters indicate significant difference ($p < .05$) within the same temperature, and different lower-case letters indicate significant difference ($p < .05$) when compared to all treatments. Table 1 shows the treatment codes

Although this is the first time the uvaia fruit drying was studied, there are few studies in the literature with uvaia derivates. Ramos et al. (2017) evaluated the convective drying of uvaia by-products, with and without centrifugation as a pre-treatment, using temperatures of 40–80°C. They observed that higher temperatures provided fast drying and reduced drying time to 51% (60°C) and 62% (80°C) when compared to 40°C. A similar result was reported for foam-mat drying of uvaia powder at temperatures of 50–80°C, which reduced drying time by 13%–55% when compared to final drying time at 50°C (Loss & Evaristo, 2021; Toniciolli Rigueto et al., 2018).

However, although temperature rise can faster the process, this approach can also impair the product quality. According to Halder and Datta (2012), higher process temperatures (>50°C) can promote damage to the cell membrane. This can expose nutrients and bioactive compounds, degrading them, as well as reducing the product rehydration capacity.

Therefore, further approaches are necessary to improve the drying process, such as using drying accelerators, like ethanol.

In fact, it is possible to observe the combination of ethanol pre-treatment and higher temperatures reduced the processing time, although the effect of ethanol is better observed at 40°C, once at 60°C the effect of high temperature influences the effect of ethanol. Therefore, the ethanol pre-treatment reduced drying time in 7% (E10) and 20% (E20), at 60°C, and 31% (E10) and 17% (E20), at 40°C (Figure 2).

The obtained results can be compared with previous studies using fruits and vegetables and the ethanol pre-treatment. Considering the convective drying and pre-treatment by immersion in ethanol (>90% v/v), a reduction of 21% was found in apple pre-treated for 10 min and dried at 50°C (Rojas, Augusto, et al., 2020), 16% in pumpkin pre-treated for 5 min and dried at 40°C (Carvalho et al., 2020), 13.4% in apple pre-treated for 3 min and dried at 70°C (Zubernik et al., 2019), 13% in strawberry pre-treated for 2 min and

dried at 60°C (Macedo et al., 2021) and 13%–35% on guaco leaves pre-treated for 5 s and dried at 50°C and 60°C (Silva et al., 2018).

In addition, the effect of the pre-treatment with ethanol showed a particular behavior comparing the treatments at 40°C: in this drying temperature, the pre-treatment by immersion during 20 min showed a drying time slightly higher than that of 10 min (Figure 2). This behavior is different from the initially expected, which would be a progressive reduction in drying time by increasing the pre-treatment time with ethanol. This result can be found, for example, apple pre-treated for 10, 20, and 30 min and dried at 50°C (Rojas, Augusto, et al., 2020), potato pre-treated for 15 and 30 min and dried at 40°C (Guedes et al., 2021), apple pre-treated (ultrasound-ethanol combination) for 10, 20, and 30 min and dried at 60, 70, and 80°C (Amanor-Atiemoh et al., 2020).

However, different works also reported there is a maximum pre-treatment time with ethanol that affects the drying time, from which a maximum reduction is achieved. This was the case of carrots slices pre-treated for 5–180 s and dried at 70°C (Dadan & Nowacka, 2021), pineapple cylinders pre-treated (ultrasound and/or ethanol) for 7.5, 15, and 30 min, and dried at 50°C (Carvalho et al., 2021), pumpkin for 15 and 30 min and dried at 50°C (Rojas et al., 2020), and apple slices pre-treated for 5–180 s and dried at 70°C (Zubernik et al., 2019).

Therefore, the effect of ethanol pre-treatment in vegetable structure and process is more complex than initially expected, being important to better understand it for different products and considering each particular structure.

During the pre-treatment with ethanol, alcohol enters the vegetable and water simultaneously exits it, due to differences in surface tension and osmotic pressure (Rojas & Augusto, 2018b; Wang et al., 2019). Although it is still a challenge to know exactly the proportion of water and ethanol present in the sample after the pre-treatment, it was evidenced that the penetration of ethanol happens mainly in short depths (Rojas & Augusto, 2018a). In addition, ethanol promotes the increase of cell permeability through the expulsion of air and intercellular water, thinning of the cell structure due to disorganization and dissolution of components of the membrane and/or cell wall (Feng et al., 2019; Funebo et al., 2002; Rojas & Augusto, 2018a, 2018b; Rojas et al., 2019; Wang et al., 2019).

After the pre-treatment with ethanol, different mechanisms enhance drying. Firstly, the high vapor pressure and lower intermolecular forces of ethanol, when compared to the properties of pure water (Corrêa et al., 2012), can facilitate drying. However, Silva et al. (2012) discussed the drying improvement was also associated with the Marangoni Effect, which is based on the mass transfer at the interface between two fluids with different surface tensions. In fact, Carvalho et al. (2020) demonstrated that surface tension, through the Marangoni Effect, mainly influence mass transfer, while the vapor pressure mainly influences the product temperature during drying. An interesting discussion is provided by Guedes et al. (2021).

As ethanol is a solvent with higher vapor pressure, it vaporizes easily during drying, allowing the remaining solution in the sample surface richer in water than ethanol. Therefore, it forms a surface tension gradient across the sample, promoting the Marangoni Effect within the sample (Rojas & Augusto, 2018b).

However, the exposure of samples under a longer pre-treatment time (20 min) may favor the ethanol penetration when compared to shorter times (10 min), resulting in deeper penetration depths. Therefore, lower process temperature makes difficult the quick vaporization of ethanol, leading to the increased processing time for the pre-treated samples for longer periods, and have greater penetration of the solvent. In fact, Carvalho et al. (2020) reported greater residual ethanol in pineapples pre-treated for longer times. On the other hand, by using higher temperature, the ethanol vaporization is facilitated, and the expected behavior is observed (longer pre-treatment times resulted in shorter drying times). Consequently, this can explain the observed behavior in uvaia during drying at 40°C and 60°C.

Particularly, uvaia is a berry-type fruit, whose edible fraction is composed of the epicarp (peel) and fleshy mesocarp (pulp) (Jacomino et al., 2018). During pre-treatment, part of the internal and external contents is exposed in contact with ethanol. One exposed side contains the fleshy and succulent pulp, while the other contains the thin and slightly velvety epicarp—which is partially impermeable due to the presence of a wax cuticle (Carrillo-López & Yahia, 2019; Zarrouk et al., 2018).

Therefore, it should be noted the physical and structural effects of applying ethanol, transporting sample moisture during pre-treatment and drying, are dependent on the concentration of ethanol used, process temperature, pre-treatment time, and also the product structure and composition. The exact importance of each mechanism, thus, can be different for each specific system, highlighting the importance of evaluating it. This is an interesting result, demonstrating the possibilities and limitations of this emerging approach.

Figure 3 also shows the parameters of Page model ($R^2 > 0.99$). The obtained parameters did not differ statistically ($p > .05$) due to the high variability and heterogeneity of the samples. In fact, the kinetic parameter "k" was statistically different when $p < .15$ for the samples C and E10 at 40°C. Even so, the parameter "k" showed a tendency toward higher values for the drying process at 60°C when compared to the 40°C (an expected behavior), and after pre-treatment with ethanol. The "n" parameter, on the other hand, did not tend to change either by changing the temperature or pre-treatment ($p > .05$), being always close to the unit, indicating the mass transfer had a behavior similar to the pure diffusive ($n \sim 1$).

Figure 4 shows sample surface temperature during the drying process. Figures 4a and 5b show actual images, where the temperature evolution is given by the color scale, which varies from blue (lower temperature) to red (higher temperature)—the correspondent scales are given in each figure. From that data, the samples' average surface temperatures were evaluated as a function of time (Figure 4c) and moisture ratio, MR (Figure 4d).

Figure 4c and d show that ethanol impacted the uvaia surface temperature during drying. For the initial time ($t = 0$ or $MR = 1$), the pre-treated samples had lower temperatures than the control. As

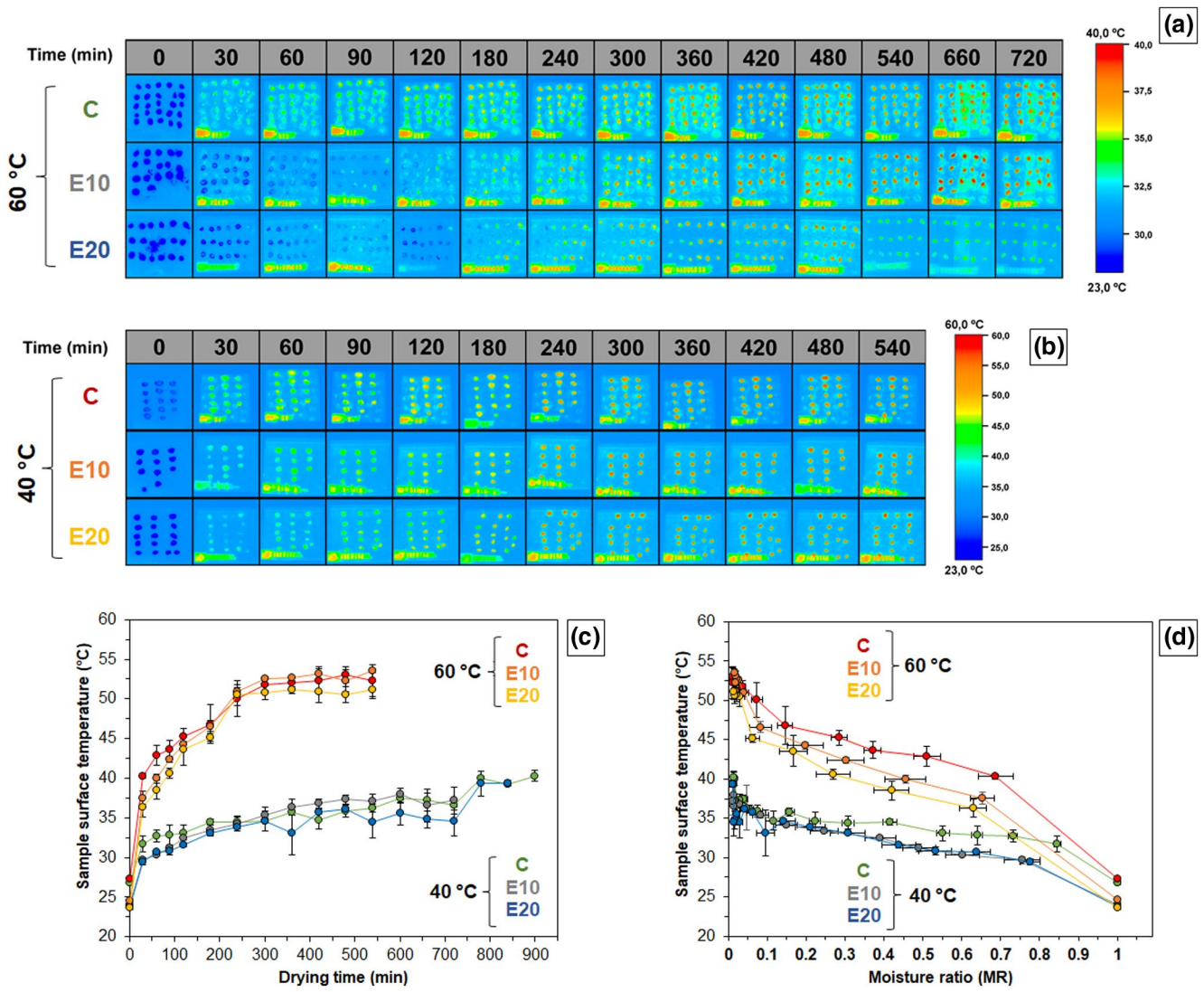

FIGURE 4 Samples surface temperature during convective drying. Thermal images of drying at (a) 40°C and (b) 60°C. Average and standard deviation of samples surface temperature as a function of (c) drying time and (d) moisture ratio (*MR*). Table 1 shows the treatment codes

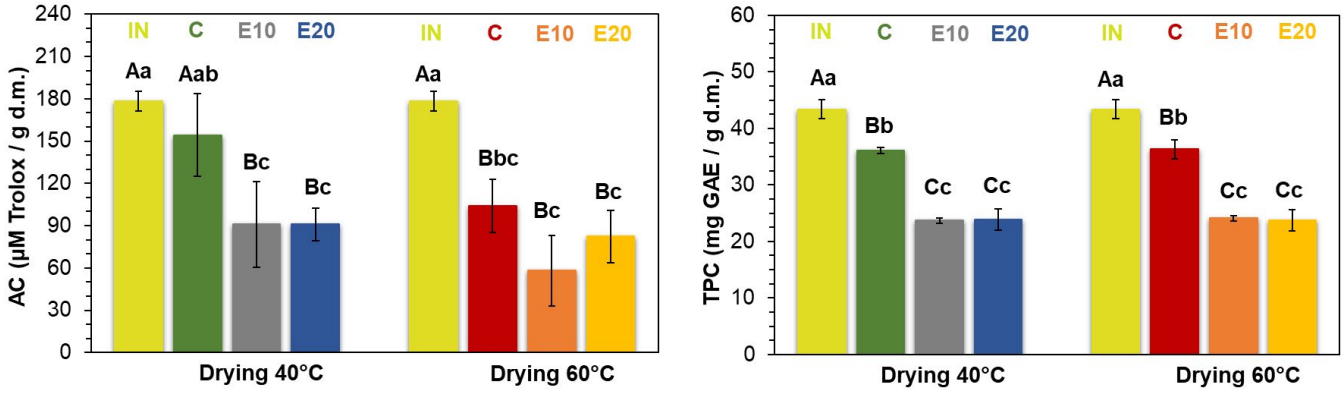

FIGURE 5 Bioactive compounds in uvaia fruit: Antioxidant capacity (AC) and Total Phenolic Content (TPC) measured in "*in natura*" fruit and after drying process at 40 and 60°C, with different pre-treatments. Vertical bars indicate the standard deviation. The superscript letters indicate Tukey Test: different upper-case letters indicate a significant difference ($p < .05$) within the same temperature, and different lower-case letters indicate a significant difference ($p < .05$) when compared to all treatments. Table 1 shows the treatment codes

ethanol has a high vapor pressure, its vaporization occurs faster than pure water, which implies a reduction in the surface temperature of the pre-treated samples. This fact was also observed in pumpkin (Carvalho et al., 2020) and pineapple cylinders (Carvalho et al., 2021).

The impact of ethanol on the reduction of surface temperature can be better observed until ~90 min of drying (Figure 4c). After that time, as the drying time progresses and the temperature increases gradually, the sample temperature behavior became similar. In addition, moisture loss occurs concomitantly with the increase in temperature, which probably reflects this approximation in temperatures.

This can be explained by the sample behavior throughout processing.

At 30 min of drying, there is a rapid increase in temperature, approximately ~5°C and ~13°C for drying at 40°C and 60°C, respectively. At this moment, there are still temperature differences among treatments, and, as expected, the samples have a high moisture content, but the rate of moisture loss is also higher. On the other hand, at 120 min of drying, the temperature of the samples is similar (Figure 4c) and the samples still have a high moisture content. After that time, the rate of moisture loss decreases (Figure 2), in which the internal moisture content influences the external heating of the samples.

Summarizing, the results indicate the pre-treatment using ethanol can accelerate the uvaia convective drying, although the effect of temperature is higher. Therefore, the product quality must be evaluated in order to verify the best approach to process this fruit.

3.2 | Bioactive compounds

Figure 5 shows the bioactive compounds (antioxidant capacity–AC and total phenolic content–TPC) in uvaia fruit, considering the different treatments. The "*in natura*" fruit (IN) presented AC value of 178.33 ± 6.83 (μM Trolox/g d.m.) and TPC 43.39 ± 1.68 (mg GAE/g d.m.).

The results of AC, expressed in μM Trolox/g d.m., were of the same magnitude for "*in natura*" fruits reported by Rufino et al. (2010) (182 ± 14.2), Branco et al. (2016) (153.09 ± 0.20), Farias et al. (2020) (83.39 ± 0.79) and freeze dried fruit reported by Ramos (2017) (191 ± 1.0). In relation to TPC for "*in natura*" fruit (expressed in mg GAE/g d.m.), similar values were reported by Pereira et al. (2012) (34.82 ± 7.41), Egea and Pereira-Netto (2019) (30.28 ± 3.28), Farias et al. (2020) (49.36 ± 0.24) and freeze dried byproduct reported by Ramos et al. (2017) (34.50 ± 5.65).

Drying reduced the concentration of both bioactive compounds, for all treatments, with the exception of conventional drying at 40°C, whose total antioxidant activity did not differ from the *in natura* sample ($p > .05$) (probably due to the large standard deviation). The drying process at 40°C reduced ~13% of the AC and ~16% of the TPC when compared with the "*in natura*" fruit, being the values for 60°C as ~42% AC and ~16% TPC.

Studies with uvaia derivatives observed similar behavior. Branco et al. (2016) evaluated the bioactive compounds from "*in natura*" uvaia and after foam-mat drying (60–70°C), reporting losses of 72%–76% of TPC. Ramos et al. (2017) showed a maximum loss of ~21% TPC in the convective drying of uvaia byproduct using temperatures of 40–80°C, without any difference between the temperatures. In addition, Ramos (2017), reported the AC contents of uvaia byproduct (the fruit skins and seeds, containing only small parts of pulp) was reduced by ~5%–7% when dried at the temperatures 40–80°C.

It is known that prolonged times of conventional drying by hot air can cause the degradation of phenolic compounds and antioxidant activity of fruits (Chong et al., 2013; Kayacan et al., 2020). Moreover, the reduction of phenolic compounds and antioxidants during drying at temperatures such as 40°C can occur due to the non-complete inactivation of oxidative enzymes (Djendoubi Mrad et al., 2012).

Although the pre-treatments using ethanol were able to reduce processing time and sample temperature, they exerted a negative impact on the bioactive compounds: the pre-treatment reduced between 20%–45% AC and 34% TPC, when compared to the respective control samples.

The reduction in the concentration of bioactive compounds may be associated with the extraction and/or degradation of these compounds during pre-treatment and/or drying. Although it is improbable to degrade those nutrients using ethanol, their extraction during the pre-treatment is possible.

In general, different compounds are responsible for the AC, such as polyphenolics, carotenoids and ascorbic acid (Chong et al., 2013; Kalt, 2005). Canteri et al. (2019) described the ethanolic solutions are capable of extracting polyphenols, some classes of lipids and proteins present in the cell wall and/or membrane. Furthermore, water and ethanol are commonly used for the extraction of polyphenols and antioxidants (Dorta et al., 2012). In fact, the extracting solvent used to compose the uvaia extract in the present work was ethanol 80% (v/v).

Similar works involving ethanol as a pre-treatment for drying demonstrate loss of AC, TCP, and other soluble compounds. Rojas, Augusto, et al. (2020) demonstrated the AC and TPC contents were reduced in apple (treated with ascorbic and citric acid) after pre-treatments (10, 20, and 30 min) through immersion in ethanol 96% (v/v). The reported loss was 37% and 42% of AC and TPC, respectively. In addition, (Zubernik et al. (2019) reported the reduction of up to 40% of TPC in apple pre-treated for 1–3 min in 96% ethanol (v/v). In the study of Feng et al. (2019), garlic slices immersed for 30 min in ethanol 75% (v/v) had their allicin content reduced by ~27% (pre-treatment) and ~70% (after pre-treatment and drying). However, in melon slices (da Cunha et al., 2020), pre-treatment by immersion of the samples for 10 min in different ethanol concentrations (50 and 100%, v/v) reduced the TPC by ~16 and 26%, respectively - although this reduction did not differ from the control.

On the other hand, it is important to highlight that pre-treatment using ethanol was able to protect other bioactive compounds during convective drying, such as carotenoids present in carrots (Santos

et al., 2021) and pumpkin (Rojas, Silveira, et al., 2020). In general, carotenoids are compounds present in the chromoplasts of plant cells and are mostly lipophilic compounds (Bartley & Scolnik, 1995; Kalt, 2005), which sometimes make their extraction difficult only with the use of ethanol, frequently requiring other organic solvents (Rodriguez, 2001).

Some bioactive compounds such as betanin, betaxanthins, ascorbic acid, and antioxidant capacity were retained in white and red pulp pitayas dried in foam mat (Araújo et al., 2020). However, in this case, the pre-treatment was carried out by drippling ethanol (95% v/v) on the sample's surfaces—differently from the present work, where the sample pieces were immersed in ethanol. This difference in pre-treatment application can explain the observed differences in the extraction of compounds.

Therefore, it should be considered that different variables can influence the content of bioactive compounds present in the final product, such as process temperature, time and type of pre-treatment, concentration of ethanol, the type of compound present and, in addition, the microstructure and particularities of the sample. Future studies are suggested to better understand the influence on the content of compounds during pre-treatment and drying of foods, as well as the residue of ethanol.

This work demonstrated a possible drawback of using ethanol pre-treatment to convective drying of fruits. However, although the treatments have reduced their TPC (expressed in mg GAE/g d.m.) and AC content (expressed in μM Trolox/g^{-1} d.m. AC), the final products still present significant values, being higher than other "*in natura*" fruits, such as umbu (7.42 ± 1.90 TPC and 77 ± 15.40 AC) and cashew apple (8.30 ± 2.65 TPC and 79.40 ± 15.70 AC) which were reported in the studies by Rufino et al. (2010), apple (5.24 ± 0.87 TPC and 8.68 ± 0.69 AC) (Rojas, Augusto, et al., 2020), kiwi fruit (3.81 TPC and 8.84 AC) (Izli et al., 2017) acerola residue (4.46 ± 0.16 TPC) (Silva et al., 2016).

Therefore, ethanol pre-treatment improved the convective drying of uvaia, and even after the process, the samples still showed relevant values of AC and TPC. This result is interesting by preserving the fruit, besides adding value to it, obtaining a healthy product.

4 | CONCLUSIONS

The ethanol pre-treatment and convective drying at different temperatures were studied for the first time for uvaia fruit, also evaluating the impact on the bioactive compounds. The parameters of the Page model showed a behavior similar to pure diffusion ($n \sim 1$) during uvaia drying. High reductions in drying time (~50%) were obtained by increasing the temperature from 40°C to 60°C. Pre-treatment with ethanol reduced the drying time up to 31%. The effect of ethanol was best observed at 40°C than at 60°C. Furthermore, the sample immersion time in ethanol influenced the reduction of drying time in different temperatures, that were associated with the penetration and vaporization of ethanol in the sample. The low vapor pressure of ethanol provided lower initial temperature of the samples, which was rapidly increased concomitantly with the loss of moisture. The drying process reduced the content of the bioactive compound in uvaia. After drying, the antioxidant capacity values were more affected, followed by the phenolic compounds. The pre-treatment with ethanol intensified those losses, which were associated with possible extractions.

The results emphasize that pre-treatment with ethanol positively impacts the drying process, which can be used as a simple method for uvaia preservation. However, a limitation of this approach is the reduction of soluble bioactive compounds. Therefore, new studies must be evaluated to improve the process concomitantly with the retention of those compounds.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Bruna de Oliveira Gomes: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Validation; Visualization; Writing – original draft. **Karoline Costa Santos:** Conceptualization; Formal analysis; Investigation; Methodology; Validation; Writing – review & editing. **Gisandro Reis de Carvalho:** Conceptualization; Formal analysis; Investigation; Methodology; Validation; Writing – review & editing. **Jaqueline Souza Guedes:** Conceptualization; Formal analysis; Investigation; Methodology. **Bruna Sousa Bitencourt:** Conceptualization; Formal analysis; Investigation; Methodology. **Pedro E D Augusto:** Conceptualization; Formal analysis; Methodology; Project administration; Resources; Supervision; Writing – review & editing.

DATA AVAILABILITY STATEMENT

Availability of data and material. All data generated or analyzed during this study are included in this published article.

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REFERENCES

Amanor-Atiemoh, R., Zhou, C., Abdullaleef Taiye, M., Sarpong, F., Wahia, H., Amoa-Owusu, A., Ma, H., & Chen, L. I. (2020). Effect of ultrasound-ethanol pretreatment on drying kinetics, quality parameters, functional group, and amino acid profile of apple slices using pulsed vacuum drying. *Journal of Food Process Engineering*, *43*(2), e13347. https://doi.org/10.1111/jfpe.13347

Araújo, C. D. S., Corrêa, J. L. G., Dev, S., Macedo, L. L., Vimercati, W. C., Rodrigues de Oliveira, C., & Pio, L. A. S. (2020). Influence of pretreatment with ethanol and drying temperature on physicochemical and antioxidant properties of white and red pulp pitayas dried in foam mat. *Drying Technology*, 1–10. https://doi.org/10.1080/07373937.2020.1809446

Bartley, G. E., & Scolnik, P. A. (1995). Plant carotenoids: Pigments for photoprotection, visual attraction, and human health. *The Plant Cell*, *7*(7), 1027. https://doi.org/10.2307/3870055

Bitencourt, B. S., Correa, J. L. G., Carvalho, G. R., & Augusto, P. E. D. (2021). *Valorization of pineapple pomace for food or feed: Effects of pre-treatment with ethanol on convective drying and quality properties*. Waste and Biomass Valorization, in press. https://doi.org/10.1007/s12649-021-01659-9

Branco, I. G., Kikuchi, T. T., Argandoña, E. J. S., Moraes, I. C. F., & Haminiuk, C. W. I. (2016). Drying kinetics and quality of uvaia (*Hexachlamys edulis* (O. Berg)) powder obtained by foam-mat drying. *International Journal of Food Science & Technology*, *51*(7), 1703–1710. https://doi.org/10.1111/ijfs.13145

Canteri, M. H. G., Renard, C. M. G. C., Le Bourvellec, C., & Bureau, S. (2019). ATR-FTIR spectroscopy to determine cell wall composition: Application on a large diversity of fruits and vegetables. *Carbohydrate Polymers*, *212*(December 2018), 186–196. https://doi.org/10.1016/j.carbpol.2019.02.021

Carrillo-López, A., & Yahia, E. M. (2019). Morphology and anatomy. In E. M. Yahia (Ed.), *Postharvest physiology and biochemistry of fruits and vegetables* (pp. 113–130). Elsevier. https://doi.org/10.1016/B978-0-12-813278-4.00006-3

Carvalho, G. R., Massarioli, A. P., Alvim, I. D., & Augusto, P. E. D. (2021). Iron-fortified pineapple chips produced using microencapsulation, ethanol, ultrasound and convective drying. *Food Engineering Reviews*, *13*(3), 726–739. https://doi.org/10.1007/s12393-020-09259-4

Carvalho, G. R., Rojas, M. L., Silveira, I., & Augusto, P. E. D. (2020). Drying accelerators to enhance processing and properties: Ethanol, isopropanol, acetone and acetic acid as pre-treatments to convective drying of pumpkin. *Food and Bioprocess Technology*, *13*(11), 1984–1996. https://doi.org/10.1007/s11947-020-02542-6

Chong, C. H., Law, C. L., Figiel, A., Wojdyło, A., & Oziembłowski, M. (2013). Colour, phenolic content and antioxidant capacity of some fruits dehydrated by a combination of different methods. *Food Chemistry*, *141*(4), 3889–3896. https://doi.org/10.1016/j.foodchem.2013.06.042

Corrêa, J. L. G., Braga, A. M. P., Hochheim, M., & Silva, M. A. (2012). The influence of ethanol on the convective drying of unripe, ripe, and overripe bananas. *Drying Technology*, *30*(8), 817–826. https://doi.org/10.1080/07373937.2012.667469

da Cunha, R. M. C., Brandão, S. C. R., de Medeiros, R. A. B., da Silva Júnior, E. V., Fernandes da Silva, J. H., & Azoubel, P. M. (2020). Effect of ethanol pretreatment on melon convective drying. *Food Chemistry*, *333*(June), 127502. https://doi.org/10.1016/j.foodchem.2020.127502

da Silva, A. P. G., Spricigo, P. C., Purgatto, E., de Alencar, S. M., Sartori, S. F., & Jacomino, A. P. (2019). Chemical composition, nutritional value and bioactive compounds in six uvaia accessions. *Food Chemistry*, *294*(November), 547–556. https://doi.org/10.1016/j.foodchem.2019.04.121

Dadan, M., & Nowacka, M. (2021). The assessment of the possibility of using ethanol and ultrasound to design the properties of dried carrot tissue. *Applied Sciences*, *11*(2), 689. https://doi.org/10.3390/app11020689

Djendoubi Mrad, N., Boudhrioua, N., Kechaou, N., Courtois, F., & Bonazzi, C. (2012). Influence of air drying temperature on kinetics, physicochemical properties, total phenolic content and ascorbic acid of pears. *Food and Bioproducts Processing*, *90*(3), 433–441. https://doi.org/10.1016/j.fbp.2011.11.009

Dorta, E., Lobo, M. G., & Gonzalez, M. (2012). Reutilization of mango byproducts: Study of the effect of extraction solvent and temperature on their antioxidant properties. *Journal of Food Science*, *77*(1), C80–C88. https://doi.org/10.1111/j.1750-3841.2011.02477.x

Egea, M. B., & Pereira-Netto, A. B. (2019). Bioactive compound-rich, virtually unknown, edible fruits from the Atlantic Rainforest: Changes in antioxidant activity and related bioactive compounds during ripening. *European Food Research and Technology*, *245*(5), 1081–1093. https://doi.org/10.1007/s00217-018-3208-z

Farias, D. D. P., de Araújo, F. F., Neri-Numa, I. A., Dias-Audibert, F. L., Delafiori, J., Catharino, R. R., & Pastore, G. M. (2020). Distribution of nutrients and functional potential in fractions of *Eugenia pyriformis*: An underutilized native Brazilian fruit. *Food Research International*, *137*(May), 109522. https://doi.org/10.1016/j.foodres.2020.109522

Feng, Y., Zhou, C., ElGasim A. Yagoub, A., Sun, Y., Owusu-Ansah, P., Yu, X., Wang, X., Xu, X., Zhang, J., & Ren, Z. (2019). Improvement of the catalytic infrared drying process and quality characteristics of the dried garlic slices by ultrasound-assisted alcohol pretreatment. *LWT*, *116*(August), 108577. https://doi.org/10.1016/j.lwt.2019.108577

Funebo, T., Ahrne, L., Prothon, F., Kidman, S., Langton, M., & Skjoldebrand, C. (2002). Microwave and convective dehydration of ethanol treated and frozen apple – physical properties and drying kinetics. *International Journal of Food Science and Technology*, *37*(6), 603–614. https://doi.org/10.1046/j.1365-2621.2002.00592.x

Guedes, J. S., Santos, K. C., Castanha, N., Rojas, M. L., Matta Junior, M. D., Lima, D. C., & Augusto, P. E. D. (2021). Structural modification on potato tissue and starch using ethanol pre-treatment and drying process. *Food Structure*, *29*(August 2020), 100202. https://doi.org/10.1016/j.foostr.2021.100202

Halder, A., & Datta, A. K. (2012). Surface heat and mass transfer coefficients for multiphase porous media transport models with rapid evaporation. *Food and Bioproducts Processing*, *90*(3), 475–490. https://doi.org/10.1016/j.fbp.2011.10.005

Haminiuk, C. W. I., Plata-Oviedo, M. S. V., Guedes, A. R., Stafussa, A. P., Bona, E., & Carpes, S. T. (2011). Chemical, antioxidant and antibacterial study of Brazilian fruits. *International Journal of Food Science & Technology*, *46*(7), 1529–1537. https://doi.org/10.1111/j.1365-2621.2011.02653.x

Izli, N., Izli, G., & Taskin, O. (2017). Drying kinetics, colour, total phenolic content and antioxidant capacity properties of kiwi dried by different methods. *Journal of Food Measurement and Characterization*, *11*(1), 64–74. https://doi.org/10.1007/s11694-016-9372-6

Jacomino, A. P., da Silva, A. P. G., de Freitas, T. P., & de Paula Morais, V. S. (2018). Uvaia— Eugenia pyriformis Cambess. In S. Rodrigues, E. de Oliveira Silva, & E. S. de Brito (Eds.), *Exotic fruits* (pp. 435–438). Elsevier. https://doi.org/10.1016/B978-0-12-803138-4.00058-7

Kalt, W. (2005). Effects of production and processing factors on major fruit and vegetable antioxidants. *Journal of Food Science*, *70*(1), 11–19. https://doi.org/10.1111/j.1365-2621.2005.tb09053.x

Kayacan, S., Karasu, S., Akman, P. K., Goktas, H., Doymaz, I., & Sagdic, O. (2020). Effect of different drying methods on total bioactive compounds, phenolic profile, in vitro bioaccessibility of phenolic and HMF formation of persimmon. *LWT*, *118*(November 2019), 108830. https://doi.org/10.1016/j.lwt.2019.108830

Llavata, B., García-Pérez, J. V., Simal, S., & Cárcel, J. A. (2020). Innovative pretreatments to enhance food drying: A current review. *Current Opinion in Food Science*, *35*, 20–26. https://doi.org/10.1016/j.cofs.2019.12.001

Loss, R. A., & Evaristo, M. (2021). *Kinetic study and physical and chemical characteristics of the grape pole and temperature function*. Retrieved from https://ciagro.institutoidv.org/ciagro2021/uploads/197.pdf

Macedo, L. L., Corrêa, J. L. G., da Silva Araújo, C., Vimercati, W. C., & Júnior, I. P. (2021). Convective drying with ethanol pre-treatment of strawberry enriched with isomaltulose. *Food and Bioprocess Technology*, *14*(11), 2046–2061. https://doi.org/10.1007/s11947-021-02710-2

Mujumdar, A. S. (2020). Handbook of industrial drying. In A. S. Mujumdar (Ed.), *Handbook of industrial drying*. Boca Raton: CRC Press. https://doi.org/10.1201/9780429289774

Page, G. E. (1949). *Factors influencing the maximum rates of air drying shelled corn in thin layers* (Purdue University). Purdue University. Retrieved from https://search.proquest.com/docview/301817819?accountid=14643

Pereira, M. C., Steffens, R. S., Jablonski, A., Hertz, P. F., de O. Rios, A., Vizzotto, M., & Flôres, S. H. (2012). Characterization and antioxidant potential of brazilian fruits from the myrtaceae family. *Journal of Agricultural and Food Chemistry*, *60*(12), 3061–3067. https://doi.org/10.1021/jf205263f

Ramirez, M. R., Schnorr, C. E., Feistauer, L. B., Apel, M., Henriques, A. T., Moreira, J. C. F., & Zuanazzi, J. Â. S. (2012). Evaluation of the polyphenolic content, anti-inflammatory and antioxidant activities of total extract from *Eugenia pyriformes* cambess (Uvaia) fruits. *Journal of Food Biochemistry*, *36*(4), 405–412. https://doi.org/10.1111/j.1745-4514.2011.00558.x

Ramos, K. K., Lessio, B. C., Mecê, A. L. B., & Efraim, P. (2017). Mathematical modeling of uvaia byproduct drying and evaluation of quality parameters. *Food Science and Biotechnology*, *26*(3), 643–651. https://doi.org/10.1007/s10068-017-0078-2

Ramos, K. K. (2017). *Aproveitamento de subproduto do processamento de frutas nativas da Mata Atlântica em cofeitos. Tese (Doutorado em Tecologia de Alimentos)*. Thesis (Ph.D. in Food Technology), University of Campinas.

Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine*, *26*(9–10), 1231–1237. https://doi.org/10.1016/S0891-5849(98)00315-3

Rodriguez-Amaya, D. B. (2001). *A guide to carotenoid analysis in foods*. Washington: ILSI Human Nutrition Institute Press.

Rojas, M. L., & Augusto, P. E. D. (2018a). Ethanol and ultrasound pretreatments to improve infrared drying of potato slices. *Innovative Food Science & Emerging Technologies*, *49*(April), 65–75. https://doi.org/10.1016/j.ifset.2018.08.005

Rojas, M. L., & Augusto, P. E. D. (2018b). Ethanol pre-treatment improves vegetable drying and rehydration: Kinetics, mechanisms and impact on viscoelastic properties. *Journal of Food Engineering*, *233*, 17–27. https://doi.org/10.1016/j.jfoodeng.2018.03.028

Rojas, M. L., Augusto, P. E. D., & Cárcel, J. A. (2020). Ethanol pre-treatment to ultrasound-assisted convective drying of apple. *Innovative Food Science & Emerging Technologies*, *61*(November 2019), 102328. https://doi.org/10.1016/j.ifset.2020.102328

Rojas, M. L., Silveira, I., & Augusto, P. E. D. (2019). Improving the infrared drying and rehydration of potato slices using simple approaches: Perforations and ethanol. *Journal of Food Process Engineering*, *42*(5), 1–7. https://doi.org/10.1111/jfpe.13089

Rojas, M. L., Silveira, I., & Augusto, P. E. D. (2020). Ultrasound and ethanol pre-treatments to improve convective drying: Drying, rehydration and carotenoid content of pumpkin. *Food and Bioproducts Processing*, *119*, 20–30. https://doi.org/10.1016/j.fbp.2019.10.008

Rufino, M. D. S. M., Alves, R. E., de Brito, E. S., Pérez-Jiménez, J., Saura-Calixto, F., & Mancini-Filho, J. (2010). Bioactive compounds and antioxidant capacities of 18 non-traditional tropical fruits from Brazil. *Food Chemistry*, *121*(4), 996–1002. https://doi.org/10.1016/j.foodchem.2010.01.037

Santos, K. C., Guedes, J. S., Rojas, M. L., Carvalho, G. R., & Augusto, P. E. D. (2021). Enhancing carrot convective drying by combining ethanol and ultrasound as pre-treatments: Effect on product structure, quality, energy consumption, drying and rehydration kinetics. *Ultrasonics Sonochemistry*, *70*(June 2020), 105304. https://doi.org/10.1016/j.ultsonch.2020.105304

Sganzerla, W. G., Beling, P. C., Ferreira, A. L. A., Azevedo, M. S., Ferrareze, J. P., Komatsu, R. A., & Lima Veeck, A. P. (2019). Geographical discrimination of uvaia (*Eugenia pyriformis* Cambess) by principal component analysis. *Journal of the Science of Food and Agriculture*, *99*(15), 6778–6787. https://doi.org/10.1002/jsfa.9961

Silva, M. A., Braga, A. M. P., & Santos, P. H. S. (2012). Enhancement of fruit drying: the ethanol effect. *Proceedings of the 18th International Drying Symposium (IDS 2012)*, (November), 11–15.

Silva, M. G., Celeghini, R. M. S., & Silva, M. A. (2018). Effect of ethanol on the drying characteristics and on the coumarin yield of dried guaco leaves (*Mikania laevigata* Schultz BIP. EX BAKER). *Brazilian Journal of Chemical Engineering*, *35*(3), 1095–1104. https://doi.org/10.1590/0104-6632.20180353s20160481

Silva, P. B., Duarte, C. R., & Barrozo, M. A. S. (2016). Dehydration of acerola (*Malpighia emarginata* D.C.) residue in a new designed rotary dryer: Effect of process variables on main bioactive compounds. *Food and Bioproducts Processing*, *98*, 62–70. https://doi.org/10.1016/j.fbp.2015.12.008

Simpson, R., Ramírez, C., Nuñez, H., Jaques, A., & Almonacid, S. (2017). Understanding the success of Page's model and related empirical equations in fitting experimental data of diffusion phenomena in food matrices. *Trends in Food Science & Technology*, *62*, 194–201. https://doi.org/10.1016/j.tifs.2017.01.003

Singleton, V. L., Orthofer, R., & Lamuela-Raventós, R. M. (1999). [14] Analysis of total phenols and other oxidation substrates and antioxidants by means of folin-ciocalteu reagent. *Methods in Enzymology*, *299*, 152–178. https://doi.org/10.1016/S0076-6879(99)99017-1

Toniciolli Rigueto, C. V., Micheletti Evaristo, L., Geraldi, C. A. Q., & Covre, L. (2018). Influência da temperatura de secagem de uvaia (*Eugenia pyriformis*) em camada de espuma. *Engevista*, *20*(4), 537. https://doi.org/10.22409/engevista.v20i4.9540

Wang, X., Feng, Y., Zhou, C., Sun, Y., Wu, B., Yagoub, A. E. A., & Aboagarib, E. A. A. (2019). Effect of vacuum and ethanol pretreatment on infrared-hot air drying of scallion (*Allium fistulosum*). *Food Chemistry*, *295*(March), 432–440. https://doi.org/10.1016/j.foodchem.2019.05.145

Zarrouk, O., Pinheiro, C., Misra, C. S., Fernández, V., & Chaves, M. M. (2018). Fleshy fruit epidermis is a protective barrier under water stress. In I. F. García Tejero & V. H. D. Zuazo (Eds.), *Water scarcity and sustainable agriculture in semiarid environment* (pp. 507–533). Elsevier. https://doi.org/10.1016/B978-0-12-813164-0.00020-X

Zubernik, J., Dadan, M., Cichowska, J., & Witrowa-Rajchert, D. (2019). The impact of the pre-treatment in ethanol solution on the drying kinetics and selected properties of convective dried apples. *International Journal of Food Engineering*, *16*(1–2), 1–11. https://doi.org/10.1515/ijfe-2018-0338

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