University of São Paulo
"Luiz de Queiroz" College of Agriculture

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

Bruna de Oliveira Gomes

Dissertation presented to obtain the degree of Master in Science. Area: Food Science and Technology

Piracicaba
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B.Sc. Food Science

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versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
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CONTENTS

RESUMO

Secagem da fruta uvaia (*Eugenia pyriformis* Cambess): etanol como pré-tratamento, cinética de secagem convectiva e compostos bioativos

Uvaia é uma fruta nativa da Mata Atlântica brasileira, cuja comercialização ainda é limitada devido a sua alta perecibilidade e sazonalidade. Este estudo avaliou os efeitos do pré-tratamento com etanol na secagem convectiva e seus impactos nos compostos bioativos da uvaia. Foram realizados seis tratamentos, consistindo em controle e amostras pré-tratadas por imersão em etanol (99,8% v/v) por 10 e 20 min que, posteriormente, foram submetidas a secagem convectiva (1 m/s) a 40 e 60 °C. As temperaturas das amostras foram registradas ao longo do processo de secagem e os produtos secos foram avaliados quanto ao teor de compostos fenólicos e capacidade antioxidante. O modelo de Page foi usado para avaliar os dados e estudar a cinética. O aumento da temperatura reduziu o tempo de secagem em cerca de 50%, enquanto os pré-tratamentos com etanol reduziram o tempo de processo entre 7-31%. O pré-tratamento em combinação com a temperatura influenciaram o tempo de secagem e foram associados à penetração do etanol na amostra e à volatilidade da porção líquida. A maior pressão de vapor do etanol, em relação à água, reduziu a temperatura inicial das amostras tratadas. As temperaturas de secagem e pré-tratamento reduziram os níveis de compostos bioativos, o que foi associado à degradação e possível extração por etanol. Portanto, foram discutidas as vantagens do uso do etanol como acelerador de secagem, mas também algumas limitações, principalmente no teor de compostos bioativos. Mesmo assim, foram obtidos frutos secos estáveis, contendo níveis adequados de compostos bioativos para diferentes aplicações (consumo direto ou para uso em formulações).

Palavras-chave: Secagem, Conservação de alimentos, Fruto nativo, Etanol

ABSTRACT

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

Uvaia is a native fruit from the Brazilian Atlantic Forest, whose commercialization is still limited due to its high perishability and seasonality. This study evaluated the effects of ethanol pre-treatment on convective drying and its impacts on the bioactive compounds of uvaia. Six treatments were performed, consisting of control and pre-treated samples by immersion in ethanol (99.8% v/v) for 10 and 20 min, which were subsequently conduced to convective drying (1 m/s) at 40 and 60 °C. Sample temperatures were recorded throughout the drying process and the dry products were evaluated for phenolic compounds content and antioxidant capacity. The Page model was used to evaluate the data and study the kinetics. Increasing the temperature reduced drying time by about 50%, while ethanol pre-treatments reduced processing time by 7-31%. The pre-treatment in combination with temperature influenced the drying time and were associated with the penetration of ethanol into the sample and the volatility of the liquid portion. The higher vapor pressure of ethanol, in relation to water, reduced the initial temperature of the treated samples. Drying and pre-treatment temperatures reduced the levels of bioactive compounds, which was associated with degradation and possible extraction by ethanol. Therefore, the advantages of using ethanol as a drying accelerator were discussed, as well as some limitations, mainly in the content of bioactive compounds. Even so, stable dried fruits were obtained, containing adequate levels of bioactive compounds for different applications (direct consumption or for use in formulations).

Keywords: Drying, Food preservation, Native fruit, Ethanol.

RESUMEN

Secado del fruto de uvaia (*Eugenia pyriformis* Cambess): etanol como pretratamiento, cinética de secado por convectivo y compuestos bioactivos

La uvaia es una fruta nativa de la Selva Atlántica brasileña, cuya comercialización aún es limitada debido a su alta perecibilidad y estacionalidad. Este estudio evaluó los efectos del pretratamiento con etanol sobre el secado por convección y sus impactos sobre los compuestos bioactivos de la uvaia. Se realizaron seis tratamientos, que consistieron en muestras control y pretratadas por inmersión en etanol (99,8% v/v) durante 10 y 20 min, las cuales fueron posteriormente sometidas a secado convectivo (1 m/s) a 40 y 60 °C. Las temperaturas de las muestras se registraron durante todo el proceso de secado y en los productos secos se evaluó el contenido de compuestos fenólicos y la capacidad antioxidante. Se utilizó el modelo de Page para evaluar los datos y estudiar la cinética. El aumento de la temperatura redujo el tiempo de secado en aproximadamente un 50%, mientras que los pretratamientos con etanol redujeron el tiempo de proceso en un 7-31%. El pretratamiento en combinación con la temperatura influyó en el tiempo de secado y estuvo asociado con la penetración de etanol en la muestra y la volatilidad de la porción líquida. La mayor presión de vapor del etanol, con relación al agua, redujo la temperatura inicial de las muestras tratadas. Las temperaturas de secado y pretratamiento redujeron los niveles de compuestos bioactivos, lo que se asoció con la degradación y posible extracción por etanol. Por lo tanto, se discutieron las ventajas de usar etanol como acelerador de secado, así como algunas limitaciones, principalmente en el contenido de compuestos bioactivos. Aun así, se obtuvieron frutos secos estables, que contenían niveles adecuados de compuestos bioactivos para diferentes aplicaciones (consumo directo o para uso en formulaciones).

Palabras clave: Secado, Conservación de los alimentos, Fruta nativa, Etanol

FIGURE LIST

1. INTRODUCTION

Brazil has a rich biodiversity with 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 their "*in natura*" commercialization and consumption.

An example is uvaia (*Eugenia pyriformis* Cambess.), a native fruit of the Brazilian Atlantic Forest. This fruit have a globe-shaped, with thin skin, velvety texture with a striking yellow-orange colour. Its pulp is succulent, fleshy, soft, with an exotic flavour 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 carbohydrate (fructose, glucose and sucrose), proteins, lipids, fibres, 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 using 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., 2022; 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.

Consequently, 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. HYPOTHESIS AND OBJECTIVES

2.1. Hypothesis

Convective drying promotes stability to fruit and vegetables products and can reduce post-harvest losses; however, this process takes a long time and can interfere with the bioactive compounds present. Ethanol as a pre-treatment is an alternative to improve the drying process of uvaia by reducing the process time and fruit temperature.

2.2. Objectives

The general objective of this work was to study the effect of ethanol as a pre-treatment for convective drying of uvaia fruit and its effects on drying processing and bioactive compounds.

The specific objectives of this work were:

• Evaluate the influence of ethanol pre-treatment on the convective drying kinetics of uvaia fruit, as well as the product temperature during processing;

• Evaluate the influence of different temperatures of drying, combined or not with ethanol pre-treatments at different conditions;

• Evaluate the influence of each pre-treatment condition and drying temperature on the bioactive compounds of uvaia, by determining the content of total phenolic compounds and total antioxidant capacity of the obtained products.

3. LITERATURE REVIEW

3.1. Uvaia fruit (Eugenia pyriformis Cambess) preservation

The uvaia is a fruit native to the Brazilian Atlantic Forest, which belongs to the Myrtaceae family and Eugenia genus; it is found throughout the south, southeast, midwest and northeast of Brazil, being present both in environments and forest fragments, backyards, small properties, etc (JACOMINO et al., 2018). Its fruits are known by different names, such as “uvaia do mato”, “ubaia”, “uvalha”, “orvalha” and “uvalheira” (SGANZERLA et al., 2019).

Uvaia fruits are highly appreciated for their sensory characteristics. Those fruits have a globe-shape, thin peel, velvety texture with a striking yellow-orange colour, and its fleshy, soft, and juicy pulp, very aromatic and with an exotic flavour. The seeds present are large, found from 1 to 4 per fruit (Figure 1).

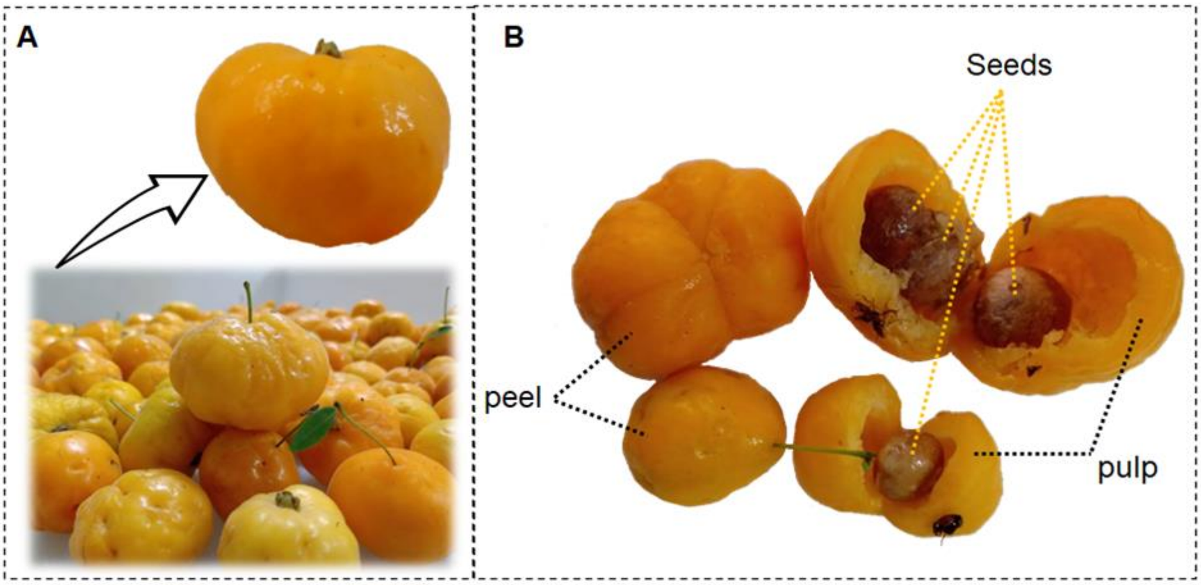

Figure 1. Uvaia fruit (A), its external and internal components (B).

In addition, uvaia fruit has properties potentially beneficial to health. It was reported that the fruit has high nutritional value and that it is composed of a range of bioactive compounds of interest, among which are phenolics and antioxidants (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). For instance, Lopes et al., (2018) demonstrated the consumption of uvaia juice by mice can be beneficial as potential modulators of oxidative stress, due to the presence of the bioactive compounds.

Therefore, uvaia has a great potential for commercial, technological and industrial exploration, not only as fresh fruit, but also for the development of different healthy products (SILVA et al., 2014).

However, in many regions of the country it is still little known and explored due to their seasonal and geographical distribution. A main limiting factor to commercialization and consumption in other regions is its high perishability, with fast changes on its physical, chemical, and sensory attributes (JACOMINO et al., 2018).

To expand the consumption and distribution of the fruit, it is important to develop processing alternatives to extent its preservation and stability (BRANCO et al., 2016). In addition, this approach can be a source of employment and development for small producers, which are concentrated in specific regions. In fact, processing can be an alternative to add value to this fruit, also developing the local communities.

In recent years, the preservation of uvaia fruit has been reported through different approaches, such as processing it as juices and pulps (ZILLO et al., 2015, 2013) sweets, jellies, liqueurs, ice cream and yogurt (JACOMINO et al., 2018; SILVA et al., 2014). In addition, some techniques have been studied, such as drying uvaia byproduct for application in confectionery (RAMOS, 2017), drying uvaia foam layer (BRANCO et al., 2016; LOSS; EVARISTO, 2021; TONICIOLLI RIGUETO et al., 2018), processing uvaia waste to obtain natural dye (AVELAR et al., 2019), and incorporation of uvaia pulp in lactose-free yogurt (BIANCHINI et al., 2020).

However, some of those techniques for processing is still limited, in special for small producers. In this context, drying is an interesting alternative for preservation, adding value and enabling its consumption.

3.2. Food drying and drying accelerators

Food drying is an ancient technique that has been applied to reduce post-harvest losses of various food products. The main purpose of drying is to reduce the water content of the product, reducing the activity of water and turning it more stable to deterioration - which can be caused by microorganisms or due to the own product metabolism. Moreover, drying reduces transport and storage costs, which can be interesting from a logistic perspective (MUJUMDAR; LAW, 2010).

Although drying achieves preservation, exposure of food to a heat source for a long time can lead to changes in the quality of the product, due to modification such as nutritional losses (loss of vitamins, loss of protein, microbial survival), chemical (tanning reaction, lipid oxidation, loss of colour) and physical (loss of aroma, shrinkage, texture) (CHOU; CHUA, 2001). Therefore, the proper choice of a drying method and its application is very important to cause less damage to the final product.

There are many food drying methods for fruits, such as infrared drying (DOYMAZ, 2012; ROJAS; SILVEIRA & AUGUSTO, 2019; SAKARE et al., 2020), microwave drying (KHRAISHEH; MCMINN & MAGEE, 2004; ZHANG et al., 2006), hybrid drying (HII et al., 2021; SONG et al., 2009). However, most of the dry foods come from convective drying, as it is simple and relatively cheaper process – important attributes if proposed for drying uvaia fruits.

Convective drying is the most employed method, which involves exposing food to a continuous flow of hot air, in which moisture vaporizes. In this process, a very complex underlying phenomenon occurs which involves the simultaneous transport of energy and mass in a hygroscopic and shrinkable system (RATTI, 2001). The phenomenon of heat and mass transfer takes place in different stages: the transfer of heat from the drying air to the food occurs, followed by the transport of water from the interior of the product to the surface, where the water than vaporizes to the air.

The hot air performs two main functions: providing latent and sensitive heat to cause the vaporization of moisture, in addition to acting as a carrier gas, carrying the water vapor formed on the surface of the food (SABAREZ, 2016). Therefore, the mass transfer phenomenon during drying can be controlled either by the rate of vaporization of moisture from the surface of the product to the drying medium (external transfer) or by the rate of diffusion of moisture (vapor or liquid) within the food matrix (transfer internal) (SABAREZ, 2016).

Even though it is a method widely applied in the food industry, convective drying is a method that consumes a lot of energy due to the long processing time and, as mentioned above, exposing the food to this long time can be quite harmful. For this, some alternatives have been studied in order to improve the drying process, such as the pre-treatments with drying accelerators – compounds added to the sample to accelerate the drying process (CARVALHO et al., 2020).

In fact, recent studies has been looking for ways to achieve shorter drying times and maximize product quality through the application of ethanol as drying accelerator (LLAVATA et al., 2020). This is a simple and promising technique, which can be applied as pre-treatment by immersion (CARVALHO et al., 2020; GUEDES et al., 2021; ROJAS & AUGUSTO, 2018a; SANTOS et al., 2021; WANG et al., 2019), surface/spray (BITENCOURT et al., 2022; CORRÊA et al., 2012), and modified atmosphere (CORRÊA et al., 2012; SILVA; BRAGA; SANTOS, 2012).

The ethanol pre-treatment has already proved to be efficient in different drying methods and different products. However, each specific matrix responds differently to each pre-treatment and process – reinforcing the need for further studies. In fact, the efficiency of ethanol pre-treatment in improving drying processes is linked to different mechanisms and strongly depends on the microstructure of the food material (BITENCOURT et al., 2022).

Funebo et al. (2002) proposed that ethanol is capable of dissolving cell wall components, which results in structural changes and greater food permeability. In a study carried out by Rojas & Augusto (2018a), changes in cell wall composition and air removal from the intercellular spaces of different plants were demonstrated.

The cell wall and membrane of vegetables have a diversified composition. According to Canteri et al. (2019), ethanolic solutions can extract polyphenols, some classes of proteins and lipids from cell walls and/or membrane. On the other hand, the compounds related to the structure of the cell wall, such as cellulose, lignin or hemicellulose, are not extracted. Therefore, once the overall cell structure is maintained, although, with thinner walls, it avoids collapsing and ensures enhanced water flux through it during both drying and rehydration process (GUEDES et al., 2021). In fact, structural changes were reported in carrots (SANTOS et al., 2021), potatoes (GUEDES et al., 2021; ROJAS & AUGUSTO, 2018b) and pumpkins (CARVALHO et al., 2020; ROJAS & AUGUSTO, 2018a) pre-treated by immersion in ethanol. Furthermore, Wang et al. (2019) pointed out improvements in the drying process due to the osmotic dehydration promoted by the ethanol pre-treatment.

Moreover, ethanol pre-treatment is an important promoter of the Marangoni Effect. As reported by Silva, Braga & Santos (2012), and demonstrated by Rojas & Augusto (2018a), during the ethanol pre-treatment, ethanol enters the cell matrix, forming an ethanol-water mixture. When the product is then dried, the vaporization of the ethanol from the interior to the surface of the sample occurs, resulting in a surface tension gradient. Due to the difference in the surface tensions of ethanol and water, water is drawn to the surface of the sample together with ethanol, resulting in the Marangoni Effect. This flow of water from the interior to the surface of the sample occurs until it finds an equilibrium in surface tension.

Another important characteristic of using ethanol pre-treatments, is the smaller temperature reached by the samples during drying, as observed for pumpkin (CARVALHO et al., 2020; ROJAS; SILVEIRA & AUGUSTO, 2020), cambuci (ROJAS et al., 2021) and pineapple pomace (BITENCOURT et al., 2022). This fact is associated with the high vapor pressure of ethanol in relation to water (CARVALHO et al., 2020), which can reduce the degradation of liable compounds – such as observed by Rojas, Silveira & AUGUSTO (2020) for carotenoids in pumpkin.

Therefore, due to its potential to increasing the drying rate, reducing processing time, the potential to obtain better-quality final product, and as being a simple technique, available even for the small producers, ethanol was chosen as the pre-treatment for the convective drying of uvaia fruit.

4. MATERIAL AND METHODS

Figure 2 represents the experiment design, including the sample preparation, pre-treatments, performed process and evaluation – which are detailed as follows.

4.1. 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 in two or four parts (approximately *2x2* 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 of 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 ºC or 60 ºC, whose codes are described in Table 1.

Table 1. Treatment codes.

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

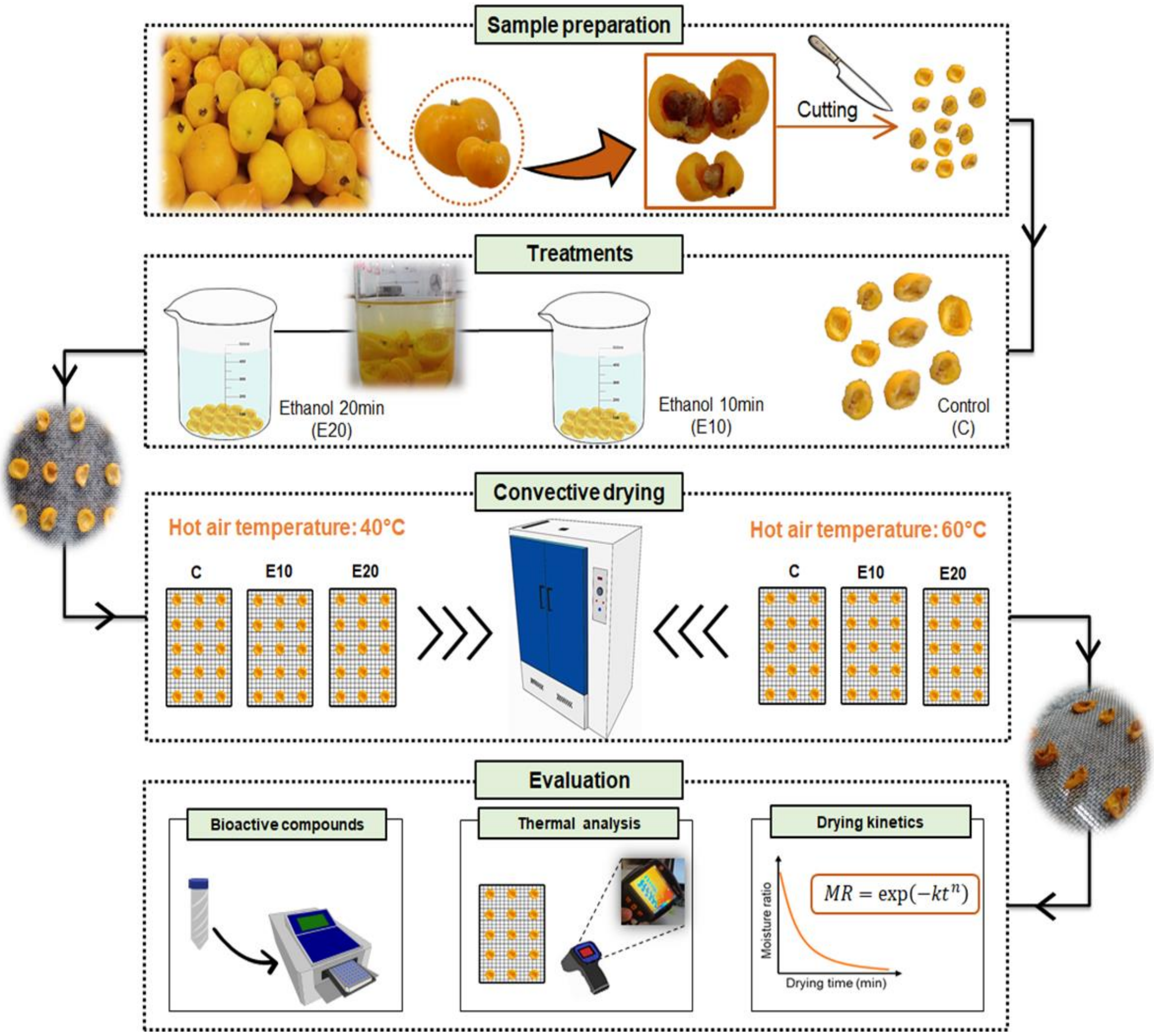

Figure 2. Representation of sample preparation, pre-treatments, performed process and analysis evaluation.

4.2. 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 2).

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, SILVEIRA, & AUGUSTO, 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 analysed using the Software IRSoft 4.5 (Text SE & Co, Germany), in which it was possible to select each sample to obtain the surface temperature behaviour 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 ethanol (ROJAS & AUGUSTO, 2018a; SILVA; BRAGA & SANTOS, 2012).

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

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

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 Eq. 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, 2018a).

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

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 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.

$$SSE = \sum_{i=1}^{X} ((Mmodel) - (Mexperimental))_i^2 \quad (3)$$

4.3. Evaluation of bioactive compounds

4.3.1. 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 & Cárcel (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 aluminium 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 h 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 x 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.

4.3.2. Antioxidant capacity (AC)

The antioxidant capacity was evaluated through the $ABTS^{\bullet +}$ 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 $ABTS^{\bullet +}$ 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 h in the absence of light. The $ABTS^{\bullet +}$ solution was diluted in ethanol until absorbance 0.7 ± 0.0025 at 734 nm, and 220 µL of the diluted $ABTS^{\bullet +}$ 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.

4.3.3. Total phenolic content (TPC)

The determination of total phenolic compounds (TPC) was carried out through colorimetric analysis by reducing the reagent Folin-Ciocalteu according to to singleton, Orthofer & Lamuela-Raventós (1999), with modifications. A calibration curve was plotted using standard solution of gallic acid (GA) 0.5 g / L (Vetec Química Ltda., Brazil). The reaction consisted of homogenizing 100 µL of 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) were 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).

4.4. 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 analysed 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.

5. RESULTS AND DISCUSSION

5.1. Convective drying

The drying kinetics, the parameters of Page Model (Equation 2) and the processing time are shown in Figures 3 and 4, for the different treatments. The drying time was estimated considering the time necessary to reach a 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 ºC for discussion (relative drying time in Figure 4).

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

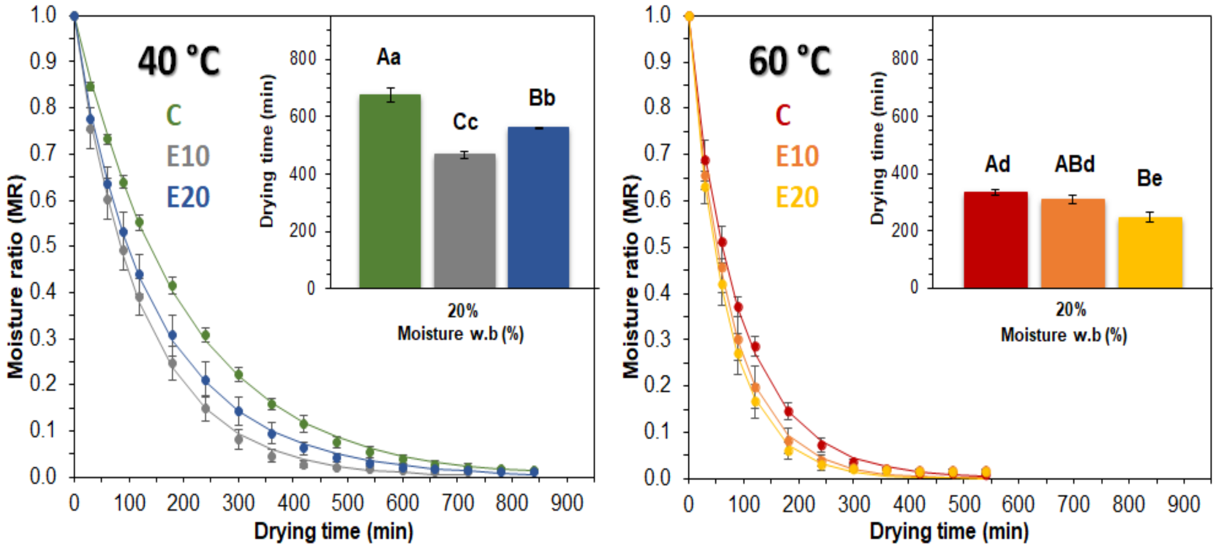

Figure 3. Uvaia convective drying behaviour at 40 °C and 60 °C. Dots are the experimental data, whose standard deviation is represented by the vertical bars. The curves are the Page Model (Equation 2). The inserted graphics represent the drying time in each treatment and superscript letters indicates Tukey Test (different upper-case letters indicate significant difference (*$p < 0.05$*) within the same temperature, and different lower-case letter indicate significant difference (*$p < 0.05$*) when compared to all treatment). Table 1 shows the treatment codes.

As expected, the temperature had a strong influence on reducing drying time (*$p < 0.05$*) (Figure 3). 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 4).

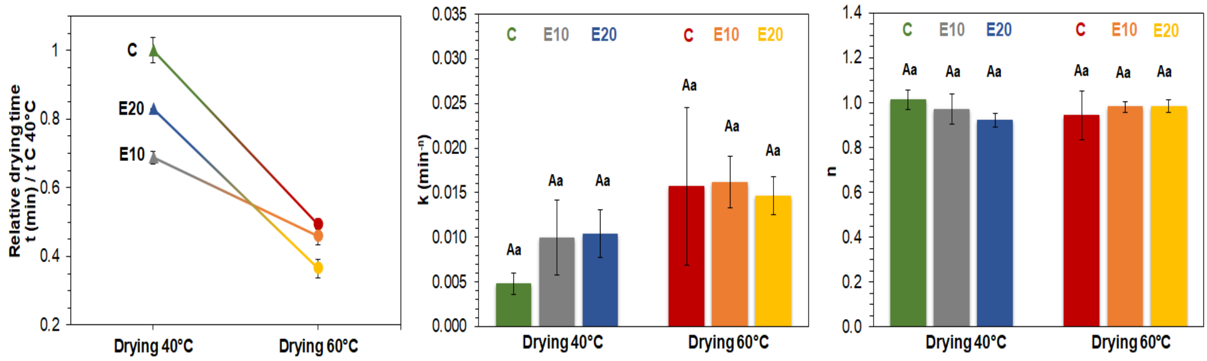

Figure 4. Relative drying time and parameters of the Page model (Equation 2), k (min^{-n}) and n, for uvaia drying at 40°C and 60°C. Averages and the standard deviations. The superscript letters indicate Tukey Test: different upper-case letters indicate significant difference ($p < 0.05$) within the same temperature, and different lower-case letters indicate significant difference ($p < 0.05$) when compared 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-product, 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. 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 & 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 reduce the product rehydration capacity.

Therefore, further approaches are necessary to improve the drying process, such as using drying accelerators, as 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 3).

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 & CÁRCEL, 2021), 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; CELEGHINI; SILVA, 2018).

In addition, the effect of the pre-treatment with ethanol showed a particular behaviour comparing the treatments at 40 ºC: in this drying temperature, the pre-treatment by immersion during 20 min showed a drying time slightly higher than that of 10 min (Figure 3). This behaviour 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 & CÁRCEL, 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; SILVEIRA & AUGUSTO, 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 difference on surface tension and osmotic pressure

(ROJAS & AUGUSTO, 2018a; 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; SILVEIRA; AUGUSTO, 2019; ROJAS; AUGUSTO, 2018a, 2018b; 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, Santos; Braga; Santos, (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 the surface tension, through the Marangoni Effect, mainly influence mass transfer, while the vapour pressure mainly influence the product temperature during drying. An interesting discussion in 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 then ethanol. Therefore, it forms a surface tension gradient across the sample, promoting the Marangoni Effect within the sample (ROJAS & AUGUSTO 2018a).

However, the exposure of samples under a longer pre-treatment time (20 min) may favour 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 increased processing time for the pre-treated samples for longer periods, and have greater penetration of the solvent. In fact, Carvalho et al. (2021) 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 behaviour is observed (longer pre-treatment times resulted in shorter drying times). Consequently, this can explain the observed behaviour in uvaia during drying at 40 ºC and 60 ºC.

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. On 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 to 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 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 ($p > 0.05$) due to high variability and heterogeneity of the samples. In fact, the kinetic parameter "*k*" were statistically different when $p < 0.15$ for the samples C and E10 at 40 °C. Even so, the parameter "*k*" showed a tendency towards higher values for the drying process at 60 °C when compared to the 40 °C (an expected behaviour), and after pre-treatment with ethanol. The "*n*" parameter, on the other hand, did not tend to change neither by changing the temperature or pre-treatment ($p > 0.05$), being always close to the unit, indicating the mass transfer had a behaviour similar to the pure diffusive ($n \sim 1$).

Figure 5 shows sample surface temperature during the drying process. Figures 5.A and 5.B show actual images, where the temperature evolution is given by the colour 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 5.C) and moisture ratio, *MR* (Figure 5.D).

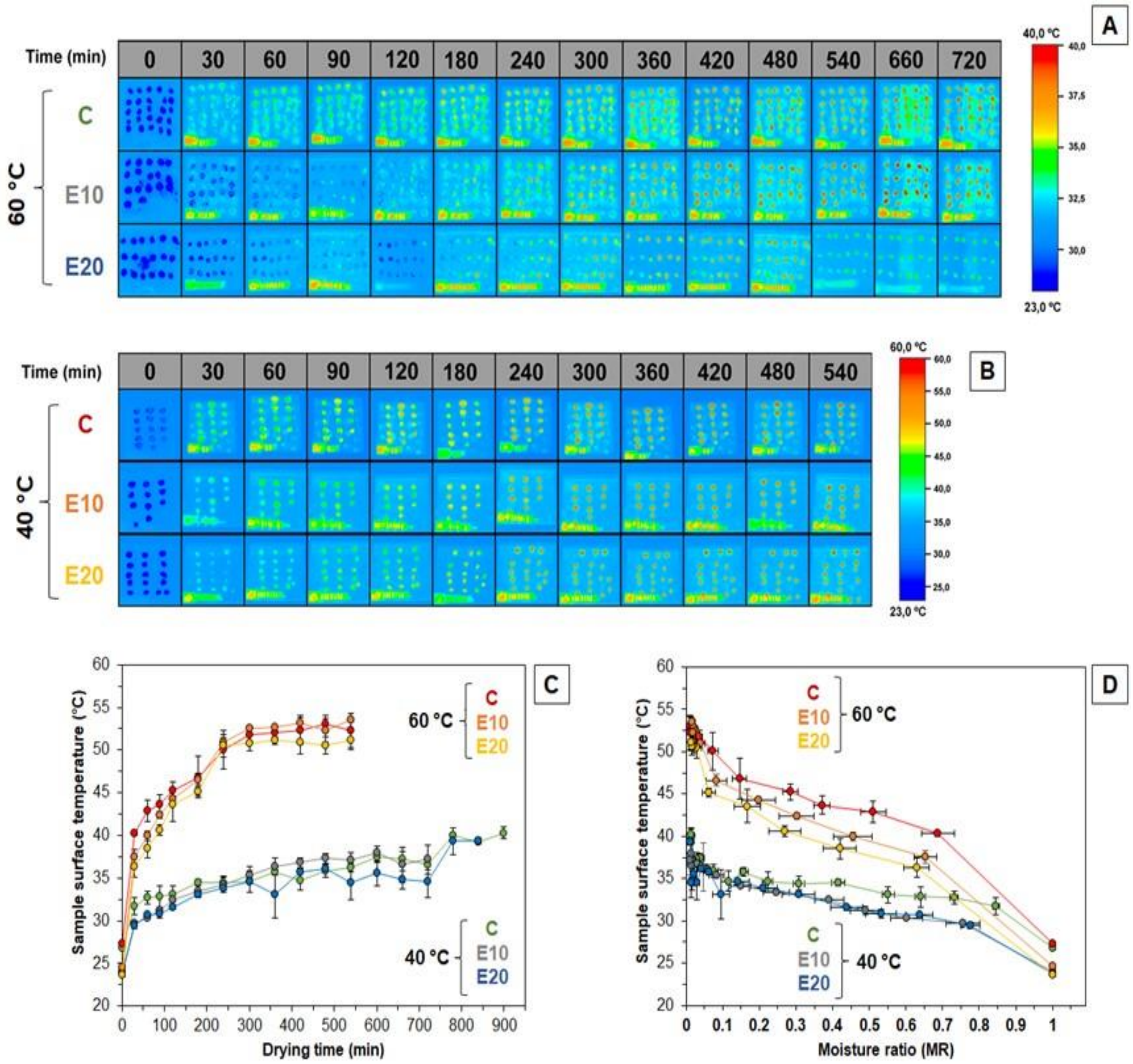

Figure 5. Samples surface temperature during convective drying. Thermal images of drying at (A) 40 °C and (B) 60 °C. Average and standard deviation of samples surface temperature as a function of (C) drying time and (D) moisture ratio (*MR*). Table 1 shows the treatment codes.

Figures 5.C and 4.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 ethanol has a high vapor pressure, its vaporization occurs faster than pure water, which implies a reduction 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 5.C). After that time, as the drying time progresses and the temperature increases gradually, the sample temperature behaviour 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 behaviour 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 is 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 5.C), and the samples still have a high moisture content. After that time, the rate of moisture loss decreases (Figure 4), 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.

5.2. Bioactive compounds

Figure 6 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 $\cdot$ g^{-1} d.m.) and TPC 43.39 ± 1.68 (mg GAE $\cdot$ g^{-1} 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 & Pereira-Netto (2019) (30.28 ± 3.28), Farias et al. (2020) (49.36 ± 0.24) and freeze dried by-product reported by Ramos et al. (2017) (34.50 ± 5.65).

Drying reduced the concentration of both bioactive compounds, for all treatments, in the exception of conventional drying at 40ºC, whose total antioxidant activity did not differ from the "*in natura"* sample ($p > 0.05$) (probably due to the large standard deviation). The drying process at 40 °C reduced ~13% the AC and ~16% the TPC when compared with the "*in natura*" fruit, being the values for 60 °C as ~42% AC and ~16% TPC.

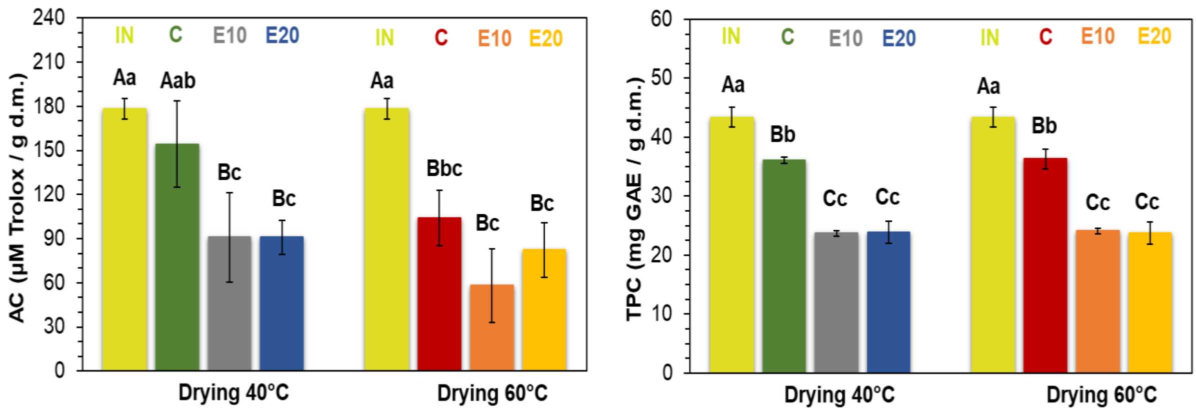

Figure 6. Bioactive compounds in uvaia fruit: Antioxidant Capacity (AC) and Total Phenolic Content (TPC) measured in "*in natura*" fruit and after drying process at 40 and 60 °C, with different pre-treatments. Vertical bars indicate the standard deviation. The superscript letters indicate Tukey Test: different upper-case letters indicate significant difference ($p < 0.05$) within the same temperature, and different lower-case letters indicate a significant difference ($p < 0.05$) when compared all treatments. Table 1 shows the treatment codes.

Studies with uvaia derivatives observed similar behaviour. 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 peels and seeds, containing only small parts of pulp) was reduced by ~5-7% when dried at the temperatures 40-80 °C.

It is known the 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 (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; LOBO & GONZALEZ, 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 demonstrates loss of AC, TCP and other soluble compounds. Rojas, Augusto & Cárcel, 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 96% ethanol (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 in ~27% (pre-treatment) and ~70% (after pre-treatment and drying). However, in melon slices (DA CUNHA et al., 2020), pre-treatment by immersion the samples for 10 min in different the 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 the 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 & AUGUSTO, 2020). In general, carotenoids are compounds present in the chromoplasts of plant cells and are mostly lipophilic compounds (BARTLEY; SCOLNIK, 1995), 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., 2022). 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 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 particularity of the sample. Future studies are suggested to better understand that 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 the 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; CÁRCEL, 2020), kiwi fruit (3.81 TPC and 8.84 AC) (IZLI; IZLI; TASKIN, 2017) acerola residue (4.46 ± 0.16 TPC) (SILVA; DUARTE; BARROZO, 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.

6. FINAL CONSIDERATIONS

This work described the convective drying process for uvaia and the pre-treatment with ethanol for the first time. Important results were obtained, some limitations of the chosen approaches were detailed, and other issues must be described.

The displacement and collection of samples in the producing regions was a big challenge. It was necessary that the fruits were intact, without loss of water during the transport and storage, in their correct maturation stage and in a quantity, for all the treatments, replicates and evaluations, that difficulted our research. The harvest season and quantity proved to still be unpredictable.

Uvaia is a seasonal fruit and must be harvested in few months of the year, let us with a short window of opportunity. In addition, there were periods of lack of rain that influenced the flowering of the uvaia tree and obtaining fruit in the year 2021.

However, another limiting factor for conducting the work, and no less important to mention, refers to the current and global situation due to COVID-19 pandemic. This fact set back the continuation of the experiment since more than one person was needed to harvest the fruit, as well as in conducting the immediate experiment to avoid the loss of raw material.

All those challenges limited our work, but mainly our expectation in relation to what it could be. We are confident and happy with the obtained results, but it highlighted that uvaia preservation is in fact necessary and must be quickly and easily applied for small producers, to implement on their properties. This approach makes it possible to transport the dried fruits to different regions and even for other technological applications.

Many studies and development are necessary to implement an efficient chain and bring native fruits to the market.

7. 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 behaviour similar to pure diffusion (n~1) during uvaia drying. High reductions in drying time (~50%) were obtained by increasing the temperature from 40 ºC 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 rapid increased concomitantly with the loss of moisture. The drying process reduced the bioactive compounds content 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 the 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.

8. SUGGESTION FOR FUTURE RESEARCH

Through the results presented in this work, future studies can be expanded in order to describe viable alternatives to improve the characteristics of this product.

Particularly, studies regarding the microstructural characteristics present in the fruit are needed to understand their contribution to the mechanisms involved during the application of ethanol in the process. Each vegetable has unique structures and can result in variable behaviour during the application of several existing pre-treatments for the dehydration of food.

In addition to convective drying, other types of drying can also be used, such as infrared drying, infrared assisted convective drying, among others. The viability of each one in small, medium and large producers, must be compared.

Considering the quality of the dry product, other studies must evaluate the rehydration process, other nutritional and bioactive markers, as well as residual ethanol in the sample. The sensory quality must be studied not only for the dried fruit, but also for products based on it – in fact, the dried uvaia is high acid, which can limit its consumption as dried fruit, but can be interesting to be mixed with sweet products. In fact, it is interesting to expand studies referring to technological applications of the dry product, such as in confections, snacks, yogurt, ice cream, etc.

In addition, studies regarding the bioavailability and bioaccessibility of the nutritional and bioactive compounds present will allow us to understand the relationship between human the body and this product.

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APPENDIX A

Simple Abstract / Resumo Simples / Resumen Sencillo

Simple astract (English)

Uvaia is a native fruit of the Brazilian Atlantic Forest, very attractive for its pleasant flavour and aroma, in addition to being rich in nutrients. This fruit is still little known, and its market is limited, due to its high perishability and seasonality. Drying is an interesting alternative for preserving this fruit, expanding its commercialization, and adding value to it. This Master's Dissertation studied different drying approaches using a new technology (ethanol as pre-treatment) for uvaia fruit. Our results showed that drying was effective in preserving the fruit, and the application of ethanol reduced the processing time. However, part of the nutrients was extracted by ethanol, exposing limitations to this alternative. Even so, the proposed approach is simple, cheap, and viable for the preservation of this fruit even for small producers.

Resumo simples (português)

A uvaia é uma fruta Nativa da Mata Atlântica Brasileira muito atrativa pelo seu sabor e aroma agradável, além de ser rica em nutrientes. Essa fruta ainda é pouco conhecida e sua comercialização é limitada, devido à alta perecibilidade e sazonalidade. A secagem, é uma alternativa interessante para conservar esse fruto, ampliando sua comercialização e agregando valor. Nesta dissertação de Mestrado, estudamos diferentes abordagens de secagem utilizando uma nova tecnologia (etanol como pré-tratamento) para a uvaia. Nossos resultados mostraram que a secagem foi eficaz na conservação do fruto e a aplicação do etanol reduziu o tempo de processo. No entanto, parte dos nutrientes foram extraídos pelo etanol, expondo uma limitação para essa alternativa. Mesmo assim, a abordagem proposta é simples, barata e viável para a preservação do fruto até mesmo para os pequenos produtores.

Resumen sencillo (español)

La uvaia es una fruta nativa de la Selva Atlántica brasileña, muy atractiva por su agradable sabor y aroma, además de ser rica en nutrientes. Esta fruta es aún poco conocida y su mercado es limitado debido a su alta perecibilidad y estacionalidad. El secado es una alternativa interesante para la conservación de esta fruta, ampliando su comercialización y agregando valor. Esta Tesis de Maestría estudió diferentes enfoques de secado utilizando una nueva tecnología (etanol como pretratamiento) para la fruta de uvaia. Nuestros resultados mostraron que el secado fue efectivo para preservar la fruta y la aplicación de etanol redujo el tiempo de procesamiento. Sin embargo, parte de los nutrientes se extrajo con etanol, mostrando limitaciones a esta alternativa. Aun así, el enfoque propuesto es simple, barato y viable para la conservación de esta fruta incluso para los pequeños productores.

APPENDIX B

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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,

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