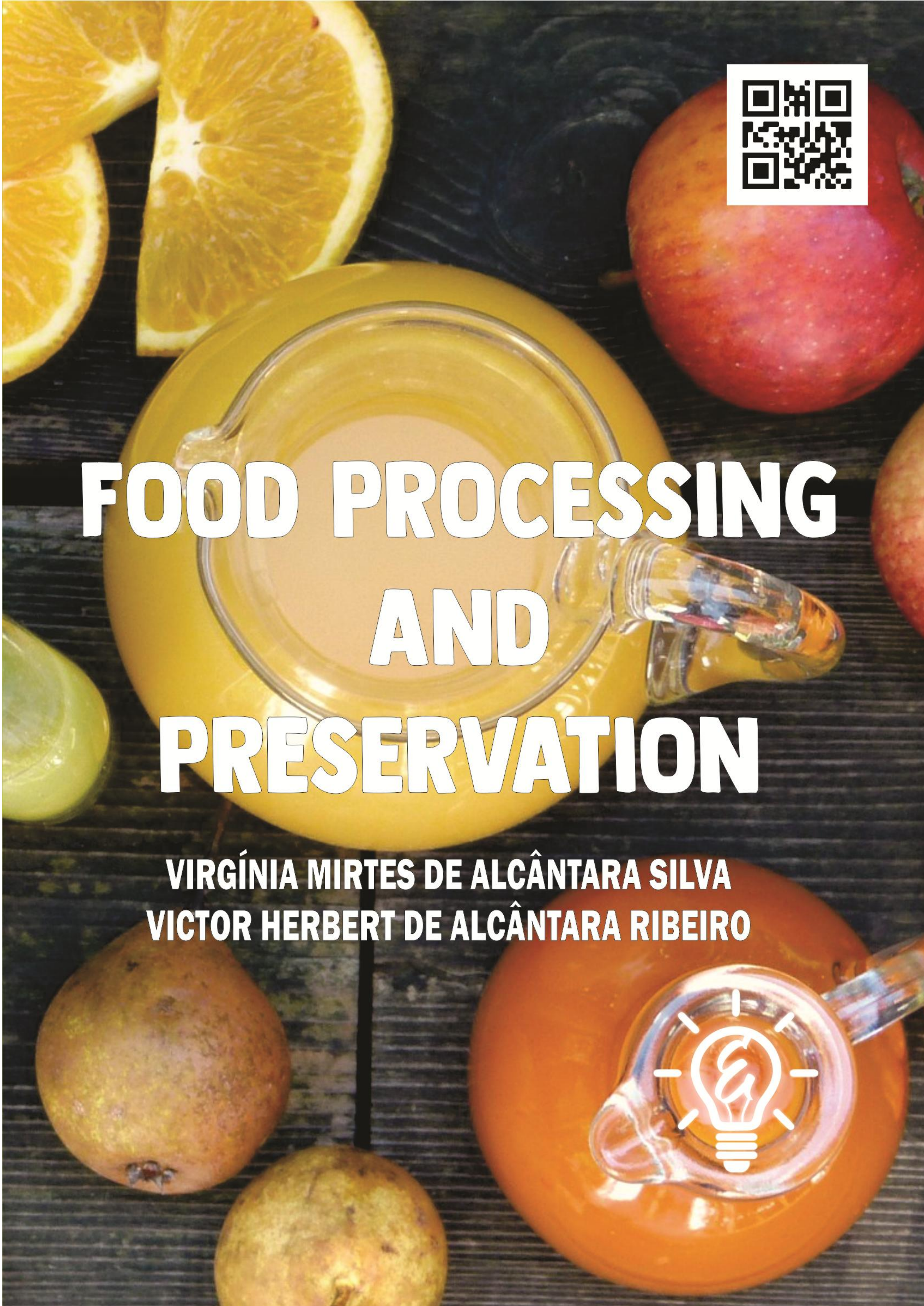

FOOD PROCESSING AND PRESERVATION

VIRGÍNIA MIRTES DE ALCÂNTARA SILVA
VICTOR HERBERT DE ALCÂNTARA RIBEIRO

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Paulo Roberto Megna Francisco

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro

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Summary

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Our special thanks to Professor Renato de Arruda Veiga for his guidance throughout the work and for choosing all the raw materials for the development of each chapter. Our recognition and dedication to Prof. Vania Moda Cirino for encouraging the correction and publication of this work.

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We hope that the work will be an effective instrument, increasingly contributing to the recognition of Brazil's innovative potential in the development of strategic foods for the world. The Work represents the effort of our team of researchers, increasingly committed to research and concern for the quality of the foods developed.

The authors

Preface

The work FOOD PROCESSING AND PRESERVATION materializes the effort of a research team with a goal of promoting a change in food systems, to stimulate regenerative ones, through the production of safe food. The disruption of various sectors, including the economic sector, caused by COVID-19 has highlighted the need to rebuild more resilient food systems, and all this involves building a food system that restores natural resources instead of depleting them.

In addition, it is necessary to emphasize population growth and the demand for animal and plant growth will require efficiency and changes in food production sectors and Brazil has the potential to promote food and nutritional security for its population.

For this to happen, technological innovation and committed research are needed, which in recent years have intensified products through their own science in the development of the use of efficient nutritional matrices. I highlight the importance of family members who already adopt these new regenerative practices and are essential.

In each chapter we observe the use of emerging techniques, green chemistry and the efficiency of the mathematical models used. The choice of strategic food matrices with nutritional value such as passion fruit, soursop and pumpkin seeds, banana peels, jackfruit berries, kale, sapodilla pulp, black rice and okra were important, as well as by-products of the agroindustry peels, stalks, seeds that are easily integrated into the development of new foods, additives and ingredients.

All the versatility of this new research team, in the choice of techniques and raw techniques and its industrial potential in development. This is an excellent instrument for applying work increasingly to an innovative potential in the world.

Marcelo Bregagnoli

Rector of the Federal Institute of Education, Science and Technology of the South of Minas Gerais

Presentation

Dr. Renato Ferraz de Arruda Veiga

Administrative Director of the Agricultural Research Support Foundation – FUNDAG.

Administrative Director of the Agricultural Research Support Foundation – FUNDAG.The year 2019, marked by the pandemic caused by Sars-Cov-2 and its variants, revealed the global fragility of food systems. Thus, improving the efficiency of agricultural and food production, in Brazil and in other countries, has become an urgent challenge. In Brazil, numerous researchers in the scientific areas, especially in agriculture, food, chemistry, biology and ecology, have intensified their research to jointly develop solutions using emerging techniques for the production and conservation of fruits, grains, vegetables, seeds, in addition to their by-products for serve as raw material for the development of new food solutions.

The main concern has been to create new paths for the agri-food system, where Brazil must be at the forefront in sustainable nutrition and food security actions, due to its installed scientific capacity, the great world producer that is in agriculture, and also for being the main country in megabiodiversity. This is made possible by promoting the development of production chains, with new products developed locally, and with food production in all seasons of the year, in addition to simultaneously increasing the preservation of the environment.

Thus, the development of this work tried to demonstrate the efficiency of several emerging techniques of food processing and conservation, using strategic raw materials with high nutritional value, such as jackfruit berries (*Artocarpus heterophyllus* Lam.), banana peels (*Musa acuminata* 'Dwarf Cavendish'), kale stems (*Brassica oleracea* L. var. medulosa), black rice pulp (*Oryza sativa* L.), okra (*Abelmoschus esculentus* (L.) Moench) and sapodilla (*Manilkara zapota* (L.) P. Royen.), and seeds of (*Cucurbita maxima* L.), soursop (*Annona muricata* L.) and passion fruit *(Passiflora edulis Sims*.).

Various technologies were used in each chapter for processing, including value-added by-products, which can be easily integrated into current food production systems, such as those that create or extract bioactive compounds with nutritional or pharmaceutical value. These use biological, physical, chemical or thermal methods and mathematical modeling to validate the efficiency of the process on the product. The methods applied, in each chapter, for the heat treatment, as well as the mathematical models used, are essential to the innovation of the processes aiming at the quality and the useful life of the products.

The applied mathematical modeling is highlighted, as it is one of the most relevant parameters to confirm the efficiency of the drying process, to characterize the physical phenomena that occur in the system, and to predict the time required to reduce the water content of the material. raw material under different drying conditions. Thus, the adjustment of the different mathematical models to the drying experimental data is essential to define which is the most appropriate mathematical model for each raw material.

I consider it relevant here to discuss each chapter individually:

Chapter 1: Deals with the proximate composition of pumpkin, soursop and passion fruit seeds. After drying, the centesimal composition refers to the percentage of the chemical composition of the food, that is, the percentage of ash, moisture, fiber, carbohydrates, lipids and proteins, obtained through analytical methods. The great particularity of this chapter is the use of strategic seeds from a nutritional point of view, since passion fruit seeds are rich in magnesium, proteins, lipids, fibers and bioactive compounds, pumpkin seeds are rich in omega-3, fiber, antioxidants and minerals such as iron and magnesium and finally soursop which is very rich in vitamins and minerals such as B1, B2, B6, calcium, magnesium, manganese and potassium.

Chapter 2: Discusses the importance of thermal (bleaching) and chemical (citric acid) treatments, evaluating their influence on drying, effective diffusivity and on the physical properties of the powder obtained. Regarding the chosen raw material, banana peels are rich in antioxidants and potassium, a source of flavonoids, carotenoids and vitamin C, rich in lutein, which contributes to the increase of melanin and tryptophan, responsible for increasing serotonin levels.

Chapter 3: Presents a combination of heat pretreatment and drying that directly affects food conservation and quality. Osmotic dehydration is a thermal pre-treatment where the product is immersed in hypertonic solutions with high osmotic pressure - such as solutions of sugars, salts or alcohols - while drying makes it possible to reduce the water content, minimizing microbial activity and product deterioration. The raw material chosen were jackfruit berries, they are rich in carbohydrates, minerals such as calcium, phosphorus, iodine, copper and iron, contain vitamins A, C and the B complex.

Chapter 4: Deals with the drying kinetics of cauliflower stalks in an electric oven and using mathematical models (empirical and diffusive) to the experimental data. Cabbage stalks are sources of important nutrients for the body to function, such as selenium, vitamins A, C and E, and zinc.

Chapter 5: Evaluates the physicochemical characteristics and determination of the sugar profile of sapodilla pulp using high performance liquid chromatography (HPLC). This is an analytical technique used to separate, identify and quantify each of the components in a mixture using a pressurized liquid (solvent) pumping system containing the sample mixture, through a column filled with a solid adsorbent material. Regarding the chosen raw material, sapodilla is a great source of vitamins A, B1, B2, B5 and C, as well as minerals such as calcium, iron, phosphorus, magnesium, potassium, silicon and sodium.

Chapter 6: Deals with ultrasound-assisted extraction kinetics of total phenolic compounds from black rice grains, at different sonication times, to determine their antioxidant activity. Black rice is rich in vitamins A, B1, B2, B6, B12, calcium, magnesium and zinc. It has 20% more protein than regular rice and is high in iron.

Chapter 7: Discusses the use of ultrasound (USM) and ethanol (ETL) heat pretreatments alone and combined in okra slices. In addition, drying kinetics of okra slices were performed and an empirical mathematical model was used to describe the process. Okra is rich in pro-vitamin A, B1, C and also has in its composition minerals such as calcium and iron, its seeds are sources of proteins and oils.

I consider this work an effective instrument that helps to highlight the potential of certain fruits and seeds, and their by-products (stalks, husks) in the development of sustainable agriculture. I hope it will serve as a guide for students, researchers, engineers and designers involved in the food industry.

COMPARATIVE STUDY OF THE CENTESIMAL COMPOSITION OF PASSION FRUIT (*Passiflora edulis*), PUMPKIN (*Cucurbita moschata* Duch.) AND GRAVIOLA (*Annona muricata* L.) SEEDS AFTER THE DRYING PROCESS

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro
Ana Carla Oliveira de Brito
Juliana Cruz Albuquerque
Fabrícia Santos Andrade
Maria Monique Tavares Saraiva
Aline Priscila de França Silva

Introduction

The fruit and vegetable processing industries generate millions of tons of significant waste by-products (peels, seeds, among others) every year, causing serious environmental problems if left untreated. These by-products have the potential to be converted into edible products and considered as raw material, low cost and accessible. They are often rich in carbohydrates, fiber, minerals and have high antioxidant activity, being a good source of nutrients and functional components (FORTES et al., 2020; VALE et al., 2019).

Passion fruit (*Passiflora edulis*) has a diuretic, anthelmintic, sedative action, helping to treat hypertension and improve menopausal symptoms. One of the characteristics that predominates in this fruit is its acidic pulp, which provides an intense flavor to its juice and derivatives (MOURA et al., 2020).

Pumpkin is a plant belonging to the *Cucurbitaceae* family, along with melon, cucumber and watermelon. In Brazil, several squash genotypes are cultivated, it presents creeping or climbing growth, extending up to six meters and its fruits differ in terms of shape, size, color, color, firmness, starch content, dry matter content, capacity storage and taste. Pumpkin fruit has high nutritional value due to the presence of substances such as carotenoids and γ-tocopherol, demonstrating anti-fatigue activity in mice (VIEIRA et al., 2019).

Soursop (*Annona muricata* L.) is a tropical fruit of high socioeconomic importance due to the increase in demand for its fresh consumption and its derivatives, making it one of the most commercially accepted fruits in the country. However, the expansion of the planted area is somewhat limited due to dormancy problems in its seeds for seedling production (REGO et al., 2018).

The storage of seeds for prolonged periods and with high water contents is practically unfeasible, because under these conditions the metabolism remains intense, in addition to favoring the growth of microorganisms, which can cause losses in the sanitary and physiological quality of the seeds, which makes drying, a fundamental factor in the production of seedlings from seeds (ISQUIERDO et al., 2020).

The drying process consists of the application of heat to the product, reducing the water content of the seeds and acting to decrease the metabolism, thus contributing to greater stability and storage for long periods, without causing the loss of its physiological quality (ULLMANN et al., 2018).

In addition, drying preserves nutrients, allowing the development of new food products with specific characteristics. Drying is an important operation in the food industry, producing safe and stable products, as well as reducing post-harvest losses (ROJAS, 2020).

The development of new strategic food products with relevant nutritional characteristics such as passion fruit, pumpkin and soursop seeds represent a challenge and only through the proximate composition (ash, moisture, proteins, lipids and total carbohydrates) can the presence of these nutrients be validated. The centesimal composition is fundamental, as this method allows the quantification of the theory of moisture, ash, proteins, foods, vitamins, fibers, lipids and, in 100g of the sample, the caloric value and food can be estimated (CAMPOS, 2010).

Several works in the literature described the proximate composition of seeds used for the development of new products in several countries (DANTHINE et al., 2022; MANDIM et al., 2022; MERELES et al., 2021) and in Brazil (ALMEIDA et al., 2021; SILVA et al., 2019; POLESE et al., 2019; MARINI et al., 2018).

In this context, the present study aims to apply the drying process to passion fruit, pumpkin and soursop seeds and compare their proximate composition.

Methodology

Raw material

For the elaboration of this work passion fruit (*Passiflora edulis*), pumpkin (*Cucurbita*) and soursop (*Annona muricata* L.) were used.

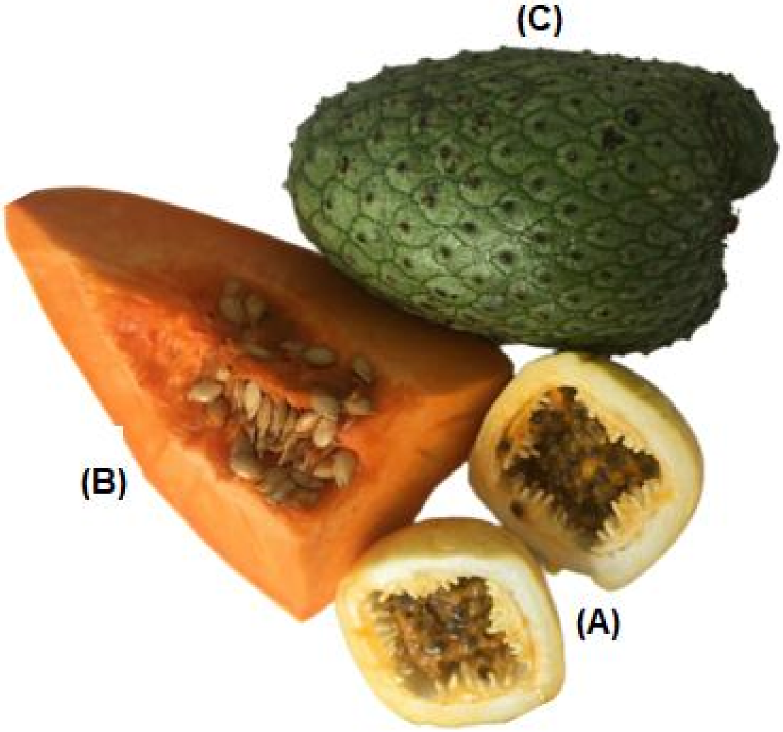

Figure 1. Passion fruit (*Passiflora edulis*) (A); pumpkin (*Cucurbita*); (B) soursop (*Annona muricata* L.); (C) used in the samples.

Obtaining the seeds

Initially, the fruits were sanitized, sanitized (200ppm sodium hypochlorite) and washed in running water. After this step, they were manually pulped and the seeds were separated from the other fractions.

Seed drying

The seeds of passion fruit (*Passiflora edulis*) (Figure 1A), pumpkin (*Cucurbita*) (Figure 1B) and soursop (*Annona muricata* L.) (Figure 1C) were dried in an electric oven for 4 hours. The drying temperature was 55°C and it was controlled using a digital thermostat.

A)

B)

C)

Figure 1. Passion fruit (A), pumpkin (B) and soursop (C) seeds used in the development of the work.

Seed storage

After the drying process, the seeds, when they reached room temperature, were stored in aluminum zip lock packages and kept at a temperature of 25°C until the composition analyzes were carried out.

Centesimal composition of seeds

The seeds after the drying process were characterized as to the following parameters:

Moisture content was determined by drying in an oven at 105 °C until constant weight (BRASIL, 2008).

Ash content was determined by muffle incineration (BRASIL, 2008).

Total protein content was quantified by the Micro-Kjeldahl method, which consisted in the determination of total nitrogen according to the methodology described by Brasil (2008).

Lipid content was quantified by the modified method of Blig and Dyer (1959). Total carbohydrate content was calculated by difference to obtain 100% of the total composition (FAO, 2003).

Statistical analysis

Experimental data were analyzed in triplicate and the results were submitted to a 5% probability single-factor analysis of variance (ANOVA) and the significant qualitative responses were submitted to the Tukey test, adopting the same 5% significance level. For the development of statistical analysis, the Assistat 7.7 software was used (SILVA & AZEVEDO, 2016).

Results

Table 1 shows the results obtained for the moisture content of passion fruit, pumpkin and soursop seeds after being subjected to the drying process.

Table 1. Moisture content of passion fruit, pumpkin and soursop seeds after the drying process

Seeds	Moisture (%)
Passion fruit	4.12 ± 0.01c
Pumpkin	5.02 ± 0.03b
Soursop	9.21 ± 0.06a

Note: Different letters in the same column differ significantly by Tukey 's test.

The moisture content found in the seeds after the drying process was less than 10%, being 4.12% for passion fruit seeds, 5.02% for pumpkin seeds and 9.21% for soursop seeds. These determined levels were significantly different from each other. Valeriano et al. (2019) obtained moisture content ranging from 2.22 to 6.48% for sesame seed varieties. Ferreira et al. (2020) when dehydrating pumpkin seeds at a temperature of 60°C for 24 hours, obtained a moisture content of 5.25%.

Moisture is a factor that, according to the Adolf Lutz Institute (BRASIL, 2008), is present in all foods, referring to the free water content contained on the surface of the same, which is important to characterize the food as very perishable. or not, or the bound water found inside these products. Table 2 presents the results obtained for the protein content of passion fruit, pumpkin and soursop seeds.

Table 2. Protein content of passion fruit, pumpkin and soursop seeds after the drying process

Seeds	**Proteins (%)**
Passion fruit	11.17 ± 0.04b
Pumpkin	21.46 ± 0.12a
Soursop	10.85 ± 0.09c

Note: Different letters in the same column differ significantly by Tukey 's test.

Significant statistical differences are observed in the protein content. Pumpkin seeds had the highest content for this parameter (24.46%). Câmara et al. (2020) obtained a protein content of 13.13% for quinoa seeds. Rinaldi et al. (2021). obtained protein contents ranging from 24.25 to 25.24% for baru seeds obtained from different locations.

proteins, it is known that those of animal origin have greater biological value compared to vegetable proteins. However, low-income populations have limited access to animal proteins (BRUZIQUESI & SOUSA, 2021).

With the increase in the world human population estimated by 2050 a demand for essential plant origin for nutrition, the proportion will be higher protein in the human diet. proteins rich in proteins important for health and are used as supplements (DIA, 2013).

In view of this, the development of new foods using as raw material such as vegetable proteins is growing because there are already growing technologies to obtain products with high purity, an example of better preservation of the air classification as functional properties of the protein specification. The properties of the functional functions for the use of these ingredients as concentrated ingredients, the best solution, the foam solution, the maintenance, the essential maintenance, and the essential maintenance (BOYE, ZARE & PLETCH, 2010; ASSATORY et al., 2019).

In this way, the amount of protein present in passion fruit, pumpkin and soursop seeds can be increased in the diet.

Table 3 presents the results obtained z obtained in a food result from its incineration, resulting only in the inorganic percentage for the ash content of passion fruit, pumpkin and soursop seeds.

According to Câmara et al. (2020), the ash content corresponds to the mineral or inorganic fraction of the food, being directly proportional to the concentration of minerals present in the sample.

Table 3. Ash content of passion fruit, pumpkin and soursop seeds after the drying process

Seeds	**Ash (%)**
Passion fruit	1.66± 0.02b
Pumpkin	2.76 ± 0.04a
Soursop	1.85 ± 0.01b

Note: Different letters in the same column differ significantly by Tukey 's test.

Pumpkin seeds had the highest ash content (2.76%). Statistically, the ash content of passion fruit (1.66%) and soursop (1.85%) seeds did not show significant differences between them. Values close to those of the present study were reported by Kruchinsch et al. (2018) who obtained 2.30% ash for grape seeds. Santos et al. (2019) obtained 3.60% ash in granadilla seeds.

Table 4 shows the results obtained for the lipid content of passion fruit, pumpkin and soursop seeds.

Table 4. Lipid content of passion fruit, pumpkin and soursop seeds after the drying process

Seeds	**Lipids (%)**
Passion fruit	22.11± 0.26b
Pumpkin	28.74± 0.41a
Soursop	12.41 ± 0.13c

Note: Different letters in the same column differ significantly by Tukey 's test.

Pumpkin seeds had the highest lipid content (28.74%) and soursop seeds the lowest content (12.41%). Statistically, when comparing the lipid content between the seeds under study, significant differences were observed ($p<0.05$).

Kruchinsch et al. (2018) obtained 16.1% of lipids in grape seeds. According to Haeberlin et al. (2020), seeds rich in lipids lose viability more easily than seeds rich in proteins and carbohydrates, thus compromising storage time, because during storage, lipid oxidation and an increase in the content of free fatty acids occur, which lead to inactivation of enzymes, denaturation of proteins and disruption of nucleic acids.

Although deterioration is inexorable and irreversible, the extent and speed of seed quality decline largely depends on temperature, relative humidity, seed water content and storage duration.

Table 5 shows the results obtained for the total carbohydrate content of passion fruit, pumpkin and soursop seeds after being subjected to the drying process.

Table 5. Carbohydrate content of passion fruit, pumpkin and soursop seeds after the drying process

Seeds	**Carbohydrates (%)**
Passion fruit	61.26 ± 0.44b
Pumpkin	42.02 ± 0.16c
Soursop	65.36 ± 0.2a

Note: Different letters in the same column differ significantly by Tukey 's test.

The total carbohydrate content of the seeds was higher than 42.02%. The soursop seed presented the highest percentage of this parameter (65.35%). High values of total carbohydrates may be related to the low moisture content of the material, since it was determined by the difference in its proximate composition. Statistically, the values obtained for this parameter were significantly different when compared to passion fruit, pumpkin and soursop seeds.

Vieira et al. (2020) obtained carbohydrate content ranging from 49.15% to 49.24% for pumpkin seeds submitted to the drying process in an oven and microwave, respectively. Silva et al. (2021) when dehydrating chia, linseed and sesame seeds at a temperature of 50°C, obtained carbohydrate content of 43.34, 31.57 and 27.43%, respectively. Santos et al. (2019), quantified 56% of carbohydrates in granadilla seed.

Final remarks

Through the results obtained, it can be concluded that:

The drying process was efficient to preserve the seeds, since they had a moisture content of less than 10%.

Pumpkin seeds had higher levels of lipids and carbohydrates, indicating that they are a good food source;

Low concentrations of mineral residue (ash) were observed for the three seeds under study.

The high levels of total carbohydrates show that seeds can also be a good source of dietary fiber.

Finally, as suggestions for future work, the influence of other drying temperatures, as well as other conservation techniques, on the composition of these materials can be evaluated.

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EFFECT OF PRE-TREATMENTS (THERMAL AND CHEMICAL) ON DRYING KINETICS, EFFECTIVE DIFUSIVITY AND PHYSICAL PROPERTIES OF BANANA (*Musa sp*) PEELS

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro
Ana Carla Oliveira de Brito
Juliana Cruz Albuquerque
Fabrícia Santos Andrade
Maria Monique Tavares Saraiva
Aline Priscila de França Silva

Introduction

Consumption of fruits and fruit products is known to not only promote good overall health, but also decrease the risk of various chronic diseases such as heart disease, stroke, gastrointestinal diseases, certain cancers, hypertension, diabetes-related macular degeneration. age, eye cataracts, skin diseases, decreased low-density lipoprotein (LDL) cholesterol and improved immune system function (SIDHU & ZAFAR, 2018).

Banana is a typical fruit from humid tropical regions and Brazil is the third largest producer in the world. With an estimated production of six million tons per year, it is the second most consumed fruit in the country after oranges. It is characterized by being a highly perishable food and its use as a sweet present itself as an alternative for its use. However, in the production of pulps for sweets and other derivatives, there is a large production of peels, which present higher nutrient contents than their respective edible parts, in addition to being rich sources of fiber (OLIVEIRA et al., 2009).

These residues are rich in vitamins, minerals, lipids and fibers, which are compounds that provide numerous health benefits and their use in the development of new products, in addition to reducing residues, contributes to increasing the added value of the final product (AMADEU et al., 2020).

Copper-containing enzymes such as polyphenoloxidases (PPOs) accelerate the oxidation reaction of numerous phenols and these compounds are extremely reactive molecules that can harden non-enzymatic reactions responsible for the development of complex brown polymers such as melanins. The banana peel turns black after cutting due to enzymatic browning that affects its appearance, taste and nutritional value. To reduce browning, a pre-treatment is used before processing which can be physical, chemical, thermal and non-thermal (JAH et al., 2021).

Bleaching is considered a mild heat treatment, which uses temperatures between 70 and 100°C for a few minutes, with subsequent cooling to prevent the product from remaining longer at the high temperature, which could lead to overheating and consequently in a cooking process. the same. Bleaching is a technique used both industrially and at home. The time-temperature binomial is dependent on the type of product that will be subjected to heat treatment, its size, geometry and the bleaching method to be used (immersion in hot water, exposure to steam, etc). The cooling step can also be performed by immersing the product in hot water, water jets or cold air streams (OLIVEIRA et al., 2018).

In addition to heat treatment, acidulant compounds are used to reduce enzymatic action and reduce browning in vegetables. These products keep the pH of the medium below the optimum pH of the enzyme. Commonly used acids are: citric, malic and phosphoric. In the case of citric acid, in addition to lowering the pH of the medium, it can also act as a chelating agent for the copper of the PPO enzyme and thus favor its inactivation (CHAVES PRIMO et al., 2018).

Due to the importance of the techniques used, several studies were carried out on different fruits: umbu (REIS et al., 2020); pineapple (RODRIGUES et al., 2020) and cashew and apple (NÓBREGA et al., 2017).

In this context, the present study aimed to apply heat (bleaching) and chemical (citric acid) pretreatments to banana peels and evaluate their influence on drying kinetics, effective diffusivity and physical properties of the powder obtained.

Metodology

Raw Material

For the elaboration of this work, ripe bananas (*Musa spp.*) acquired in the local trade of Campina Grande-PB were used. The bananas were sanitized and sanitized and their peels were used for the development of the present work. The peels (Figure 1) were cut into rectangles and separated into 3 batches: 1st batch (control peels), 2nd batch (physical pre-treatment) and 3rd batch (physical pre-treatment)

Figure 1. Banana peel (*Musa spp.*) after peeling without pre-treatment application.

Application of pre-treatment

Untreated or control samples (1° batch) were transferred directly to drying trays without any pre-treatment.

Bleaching

The 2nd batch of husks was subjected to a pre-bleaching treatment, in which they were blanched in hot water at 80°C for 5 min and instantly cooled with running water for 5 min to eradicate excess heat, followed by extra water drainage with the help of a stainless steel mesh, following the procedure described by Jha et al. (2021).

Citric acid solution

The 3rd batch of peels was subjected to pre-treatment in citric acid solution, in which they were dipped in a 0.2% citric acid solution for 30 min following the procedures described by Jha et al. (2021).

Drying the husks

The three batches of peels were submitted to drying kinetics at a temperature of 50°C in an air circulation oven with a fixed speed of 2.0 m s^{-1}. Moisture loss was recorded using a digital scale with a precision of 0.001g. The drying process was continued until the constant mass reading was recorded.

Calculation of diffusivity

The effective diffusivities (Def) of the shells under different conditions were determined using the diffusion equation Equation 1 for rectangular coordinate systems (CRANK, 1975). In the Def calculus, the analytical solution to Fick's second diffusion law was applied in the form of an infinite series Equation 2.

$$\frac{\partial X}{\partial t} = \frac{\partial}{\partial x}\left(Def\,\frac{\partial X}{\partial x}\right) + \frac{\partial}{\partial y}\left(Def\,\frac{\partial Y}{\partial y}\right) + \frac{\partial}{\partial z}\left(Def\,\frac{\partial Z}{\partial z}\right) \quad \text{(Eq.1)}$$

$$X^{*} = \frac{X(t) - X_{eq}}{X_i - X_{eq}} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)} \exp\left[-(2n+1)^2 \pi^2 \frac{Def}{L^2} t \right] \quad \text{(Eq.2)}$$

Where: X^{*} is the dimensionless moisture ratio; n is the number of terms; Def is the effective diffusivity ($m^2 min^{-1}$); L is the wall thickness (m); t is the time (min)

Physical properties of the powders obtained

The dehydrated peels after drying the 3 batches were crushed and the powders obtained were analyzed for the following parameters described below.

Water activity

Water activity (aw) was determined using the Decagon® Aqualab CX-2T device at 25°C.

Apparent density

The apparent density was determined using a 10 mL beaker previously weighed and then filled with banana peel powder, and determined using Equation 3 (TONON et al., 2009).

$$\rho_{ap} = \frac{m}{V} \qquad \text{(Eq.3)}$$

Where: ρ_{ap} is the apparent density ($g\ cm^{-3}$), m is the mass and V is the volume occupied.

Compacted density

The compacted density was determined from the assembly used in the apparent density, by beating the beaker filled with the sample for 50 times on the bench, from a pre-established height of 2.5 cm, calculating the ratio through from Equation 4 (TONON et al., 2009).

$$\rho_c = \frac{m}{V_c} \qquad \text{(Eq.4)}$$

Where: ρ_c is the tapped density (g cm^{-3}), m is the mass and Vc is the volume occupied after compaction.

Statistical analysis

The experimental data were analyzed in triplicate and the results were submitted to a 5% probability single-factor analysis of variance (ANOVA) and the significant qualitative responses were submitted to the Tukey test, adopting the same 5% significance level. For the development of statistical analyses, the Assistet 7.7 software was used (SILVA & AZEVEDO, 2016).

Results

Figure 2 shows the drying kinetics curves (ratio of moisture versus drying time) of banana peels without pre-treatment (1st batch-control) and with pre-treatment (2nd batch (heat pre-treatment) and 3rd batch (chemical pre-treatment)). The curves in Figure 2 represent the decrease in the water content of the product during drying, that is, it is the curve obtained by weighing the product during drying in a certain drying condition (PARK et al., 2014).

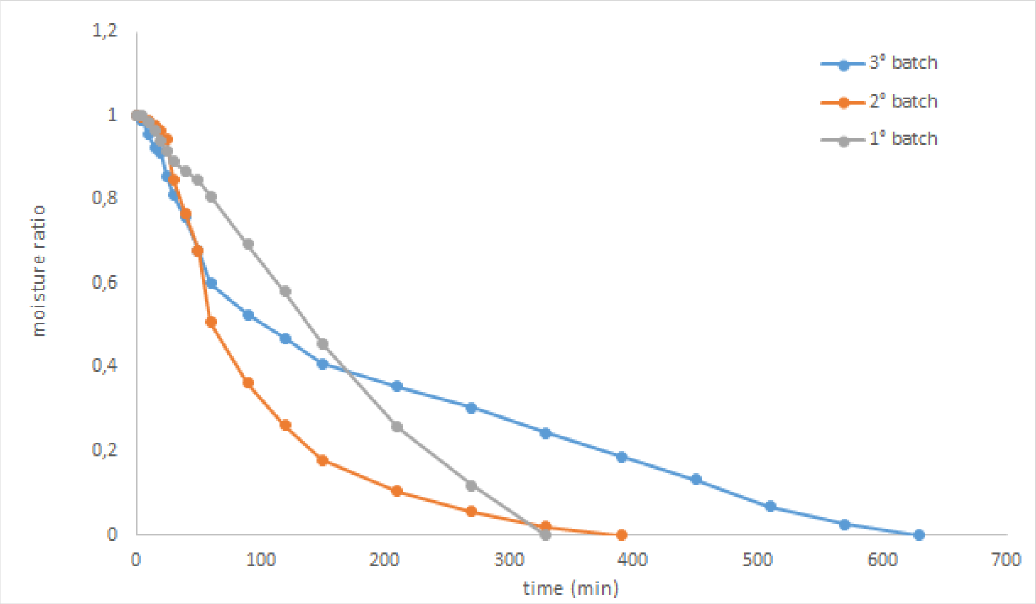

Figure 2. Moisture ratio versus drying time of banana peels subjected to pre-treatments under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment) and 3rd batch (chemical pre-treatment).

It can be seen that for the three batches of banana peels, the points are higher in the initial minutes of the process. According to Park et al. (2014) this period is called the induction period or the period of entering the operating regime, because at the beginning, the product is usually colder than air, and the partial pressure of water vapor on the surface of the product is weak, and consequently, the mass transfer and drying rate are also weak.

The heat arriving in excess causes an increase in the temperature of the product, with an increase in pressure and drying speed. This phenomenon continues until the heat transfer exactly compensates for the mass transfer. If the air temperature is lower than that of the product, the latter will decrease until reaching the same equilibrium state. The duration of this period is insignificant in relation to the total drying period.

The shells that did not receive pre-treatment took 330 min for them to reach the equilibrium water content. The peels submitted to bleaching had the 2nd longest drying time (390 min) and those submitted to chemical pre-treatment with immersion in citric acid solution showed an increase of 52.38% in drying time compared to the control peels (1st batch).

In Table 1, it is possible to observe the values of effective diffusivity (Deff), coefficient of determination (R^2) and chi-square function (χ^2), obtained in the drying process of banana peels submitted to pre-treatments under the following conditions: 1° lot (control peels), 2nd lot (heat pre-treatment) and 3rd lot (chemical pre-treatment).

Table 1. Effective diffusivity of the drying process of banana peels subjected to pre-treatments under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment), and 3rd batch (chemical pre-treatment)

Batches	**Deff (m^2 min^{-1})**	**R^2**	χ^2
1st	4.81×10^{-5}	0.9602	1.6849×10^{-2}
2nd	3.58×10^{-5}	0.9828	6.3810×10^{-2}
3rd	3.05×10^{-5}	0.9845	3.7809×10^{-2}

Note: Coefficient of determination (R^2); Chi -square function (χ^2).

The adjustment of Fick's second law of diffusion, applied in the form of an infinite series to the experimental data of the drying kinetics of banana peels under different conditions, showed a coefficient of determination greater than 0.98 (R^2>0.98) for all conditions studied, in addition, the values of the chi-square function (χ^2) were low in the order of 10^{-2} and ranged from 1.6849 – 6.3810×10^{-2}. Thus, it was considered a good fit to the experimental data.

The effective diffusivity values present values of 4.81×10^{-5} m^2 min^{-1}, 3.58×10^{-5} m^2 min^{-1} and 3.05x10-5 m^2 min^{-1}, for the 1st and 2nd samples and 3rd batch, respectively. Jah et al. (2021) when applying 4 different pre-treatments to the banana flower, obtained diffusivity values ranging from 5.9789×10^{-7} to 12.925×10^{-7} m^2 s^{-1}. Lima et al. (2020) when determining the effective diffusivity of the passion fruit peel drying process without pre-treatments, the values ranged from 2.602×10^{-7} to 2.792×10^{-7} m^2 min^{-1} for temperatures of 60 and 70°C, respectively. According to Gomes et al. (2018) diffusivity represents the speed with which water moves from the interior to the surface of the material, thus being vaporized.

Table 2 shows the values obtained for the water activity of the banana peel powder, obtained after the drying process under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment) and 3rd batch (chemical pre-treatment). According to Ferreira Neto et al. (2005), water activity has been considered a fundamental property in food quality control, since it expresses the water content that is in the free state.

Table 2. Water activity of banana peel powders subjected to pre-treatments under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment), and 3rd batch (chemical pre-treatment)

Batches	**Water activity**
1st	0.321 ± 0.01 ^{A}
2nd	0.352 ± 0.02 ^{A}
3rd	0.389 ± 0.01 ^{A}

Note: Different letters in the same column differ significantly by Tukey 's test.

The water activity of the powders obtained in the 3 conditions were lower than 0.4 (aw>0.4), statistically these observed values did not present significant differences between them. The powder obtained from drying the peels of the 3rd batch had the highest value 0.389. Nunes et al. (2017), obtained water activity ranging from 0.39 to 0.56 for pineapple peels dehydrated at 50, 60 and 70°C. The powders obtained by showed low water activity, the growth of fungi and bacteria can be hampered, in addition, the water activity has a great influence on the stability of materials during storage (FERREIRA NETO et al., 2005).

In Table 3, it is possible to observe the values obtained for the apparent density of the banana peel powder, obtained after the drying process under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment) and 3rd batch (chemical pre-treatment).

According to Ceballos et al. (2012) density analyzes are very relevant for the industry, as they can determine the amount of material that can be stored in a tank or in packaging. Density is also one of the factors that interfere with powder wettability, a very important characteristic since it consists of the first stage of reconstitution of a powder product.

Table 3. Apparent density of banana peel powders subjected to pre-treatments under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment), and 3rd batch (chemical pre-treatment)

Batches	**Apparent density (g cm^{-3})**
1st	0.341 ± 0.03 ^{A}
2nd	0.352 ± 0.01 ^{A}
3rd	0.366 ± 0.05 ^{A}

Note: Different letters in the same column differ significantly by Tukey 's test.

The apparent density is the ratio between the powder mass and the volume occupied by the powder, its values were 0.341 g cm^{-3} (1st batch), 0.352 g cm^{-3} (2nd batch) and 0.366 g cm^{-3} (3rd Lot). Statistically, these values obtained did not show significant differences between the pre-treatments applied.

Martins et al. (2019) when preparing freeze-dried blends with banana pulp and peel, they obtained apparent density ranging from 0.56 to 0.58 g cm^{-3}. In Table 4, it is possible to observe the values obtained for the compacted density of the banana peel powder, obtained after the drying process under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment) and 3rd batch (chemical pre-treatment).

Table 4. Compacted density of banana peel powders subjected to pre-treatments under the following conditions: 1st batch (control peels), 2nd batch (heat pre-treatment) and 3rd batch (chemical pre-treatment)

Batches	**Compacted density (g cm^{-3})**
1st	0.412 ± 0.05 ^{A}
2nd	0.431 ± 0.01 ^{A}
3rd	0.446 ± 0.03 ^{A}

Note: Different letters in the same column differ significantly by Tukey 's test.

The compacted density showed higher values than those obtained for apparent density, due to the smaller volume occupied by the powder. This same behavior was also observed by Silva et al. (2021). The pre-treatment did not significantly influence the values obtained for this parameter, which ranged from 0.412 g cm^{-3} to 0.446 g cm^{-3}.

Final remarks

Through the results obtained, it can be concluded that:

The pre-treatments applied were efficient to avoid the browning of the banana peels.

The drying time of the peels submitted to the pre-treatment of immersion in citric acid solution was superior when compared to the bleaching.

The model used to calculate the diffusivity was considered to be a good fit to the experimental data set and the effective diffusivity values ranged from 3.05 $x10^{-5}$ m^2 min^{-1} to $4.81x10^{-5}$ m^2 min^{-1}.

The powders obtained in the three conditions showed low water activity, being safe for storage.

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OSMOTIC DEHYDRATION AND CONVECTIVE DRYING OF JACA BERRIES (ARTOCARPUS HETEROPHYLLUS)

Virgínia Mirtes de Alcântara Silva

Victor Herbert de Alcântara Ribeiro

Ana Carla Oliveira de Brito

Juliana Cruz Albuquerque

Fabrícia Santos Andrade

Maria Monique Tavares Saraiva

Aline Priscila de França Silva

Introduction

Jackfruit (*Artocarpus heterophyllus*), from the Moraceae family, is a huge edible tropical fruit of arboreal origin. It is believed to be native to the Western Ghats of India but is now most widely cultivated in Bangladesh, Burma, Malaysia, Indonesia, Thailand and to a lesser extent Brazil and Australia. Jackfruit is rich in protein, digestible starch, minerals and vitamins. It is a fruit rich in energy indicated for the treatment of physical or mental fatigue, stress and muscle weakness and also for athletes. It has been found to exhibit antimicrobial, antidiabetic, anti-inflammatory, antioxidant and anthelmintic properties. The fruits are consumed in natura by the most diverse strata of the population and their high perishability leads to a high rate of post-harvest loss, causing losses for the producers of this fruit (SANTOS FILHO et al., 2021).

The industrialization of fruits is an alternative used with the objective of diversifying the possibilities of commercialization and increasing the shelf life of these products, thus reducing the losses in the post-harvest stages. Conservation techniques such as osmotic dehydration, drying and freezing allow these products to maintain their nutritional, sensory, chemical, physical and microbiological characteristics for a longer period of time (REIS et al., 2017).

Osmotic dehydration is a heat pretreatment that is used to remove some of the water from foods such as fruits and vegetables; is performed by immersing food in hypertonic solutions with high osmotic pressure, such as solutions of sugars, salts or alcohols. Drying is one of the most widely used techniques in fruit conservation, as it allows the reduction of water content, reducing microbial activity and product deterioration (MONTEIRO et al., 2020a).

According to Silva and Pedro (2018), osmotic dehydration has been used to minimize the adverse effects that usually appear when the product is subjected to hot air drying. This combination of drying methods has been identified as an economical and safe alternative for the conservation of food products, in addition to enabling the obtaining of better quality dehydrated products when compared to conventionally dehydrated products.

Due to the efficiency of the techniques used, studies were carried out on different fruits: mango (*Mangifera indica*) (KHUJITJARU et al., 2022); kiwi (*Actinidia Arguta*) (BIALIK et al., 2020; BROCHIER et al., 2019); cherries (Prunus *avium*)

(MALDONADO et al., 2022); physalis (*Physalis peruviana L.*) (LUCHESE et al., 2015).

Therefore, the present study aims to perform osmotic dehydration of jackfruit berries in three different sucrose concentrations (40, 50, and 60 °Brix) at a temperature of 50°C and to determine their water loss, mass loss and solid gain.

After this step, the second objective of this work is to perform the convective drying of the osmotically dehydrated berries, calculate the effective diffusivity and finally, determine the water content, water activity and total soluble solids.

Methodology

Raw material

Jackfruit (*Artocarpus heterophyllus*) was used to carry out this research (Figure 1). After acquisition, it was washed, sanitized and sanitized. The pits were removed manually, thus obtaining its berry (pulp).

Figure 1. Jackfruit and jackfruit berries.

Osmotic dehydration

The jackfruit berries were weighed and placed in properly numbered galvanized wire mesh baskets, then submerged in the osmotic solution (40, 50 and 60 °Brix) using a ratio of 1:8 (fruit:solution), and then placed in the incubator with mechanical agitation of 100 rpm at temperatures of 50°C for a time interval corresponding to 2 hours. After the predetermined time interval, the samples were removed from the solution and washed with distilled water to remove the sugar layer adhered to the surface of the sample, then they were lightly dried with absorbent paper and their masses were measured. After this step, the calculations of water loss (PA), mass loss (PM) and solids gain (GS) can be performed.

Calculation of water loss (PA)

The water loss from the berries after the osmotic dehydration process was calculated according to Equation 1.

$$PA = \frac{(Ma_0 - Ma_t)}{M_0} x100 \qquad \text{(Eq.1)}$$

Where: PA is the water loss; Ma_0 is the water content in the product; Ma_t is the - water content in the product at time t; M_0 is the initial mass of the product.

Calculation of mass loss (PM)

The weight loss of the berries after the osmotic dehydration process was calculated according to Equation 2.

$$PM = \frac{(M_0 - M_t)}{M_0} x100 \qquad \text{(Eq.2)}$$

Where: PM is the mass loss; M_0 is the initial mass of the product; M_t is the mass of the product at time t.

Calculation of solid gain (GS)

The solid gain of the berries after the osmotic dehydration process was calculated according to Equation 3.

$$GS = PA - PM \qquad \text{(Eq.3)}$$

Where: GS is the solids gain; PA is the water loss calculated in Equation 1 and PM is the mass loss calculated in Equation 2.

Drying the berries

After the osmotic dehydration process of jackfruit berries in different sucrose conditions (40, 50 and 60 °Brix) they were submitted to drying kinetics at a temperature of 50°C in an air circulation oven with a fixed speed of 1.5 m s^{-1}. Moisture loss was recorded using a digital scale with an accuracy of 0.001g. The drying process was continued until the constant mass reading was recorded.

Calculation of diffusivity

Effective diffusivities (Def) of the drying process of jackfruit berries after osmotic dehydration under different conditions (40, 50 and 60 °Brix) were determined using the diffusion equation Equation 4for rectangular coordinate systems (CRANK, 1975). In the Def calculus, the analytical solution to Fick's second diffusion law was applied in the form of an infinite series Equation (5).

$$\frac{\partial X}{\partial t} = \frac{\partial}{\partial x}\left(Def \frac{\partial X}{\partial x} \right) + \frac{\partial}{\partial y}\left(Def \frac{\partial Y}{\partial y} \right) + \frac{\partial}{\partial z}\left(Def \frac{\partial Z}{\partial z} \right) \qquad \text{(Eq.4)}$$

$$X^{*} = \frac{X(t) - X_{eq}}{X_i - X_{eq}} = \frac{8}{\pi^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)} \exp\left[-(2n+1)^2 \pi^2 \frac{Def}{L^2} t \right] \qquad \text{(Eq.5)}$$

Where: X* is the dimensionless moisture ratio; n is the number of terms; Def is the effective diffusivity (m^2 min^{-1}); L is the wall thickness (m); t is the time (min)

Physico-chemical characterization

The jackfruit berries in natura and after the combined process of osmotic dehydration and convective drying were analyzed for the following parameters described below.

Water content

The water content was determined in a vacuum oven at 70 °C until constant mass was obtained (Brasil, 2008).

Water activity

Water activity (a_w) was determined using the Decagon® Aqualab CX-2T device at 25°C (BRASIL, 2008).

Total soluble solids

The total soluble solids (TSS) content was determined using a portable Abbe-type refractometer (BRASIL, 2008).

Statistical analysis

The experimental data were analyzed in triplicate and the results were submitted to a single-factor analysis of variance (ANOVA) of 5% probability and the significant qualitative responses were submitted to the Tukey test, adopting the same level of 5% of significance. For the development of statistical analyses, the Assistet 7.7 software was used (SILVA & AZEVEDO, 2016).

Results

Table 1 presents the results obtained for the water loss of jackfruit berries subjected to osmotic dehydration in sucrose solutions with concentrations of 40, 50 and 60 °Brix.

Table 1. Mean water loss (PA) values of jackfruit berries after the osmotic dehydration process at sucrose concentrations of 40, 50 and 60 °Brix

Sucrose solution	Water loss (g/100g)
40 °Brix	32.12 ± 0.91c
50 °Brix	37.09 ± 0.65b
60 °Brix	42.92 ± 0.82a

Note: Different letters in the same column differ significantly by Tukey's test.

The water loss values were significantly influenced by the increase in sucrose concentration, in which the values increased from 32.12 g/100g to 42.92 g/100g.

Silva Junior et al. (2020) when performing osmotic dehydration of banana peels, observed a water loss of 50.74 g/100 g. Araújo et al. (2010), when studying the optimization of osmotic dehydration of red jambo at temperatures from 20 to 70°C and sucrose concentrations from 16 to 84 °Brix, observed that the increase in the concentration of the solution favored the loss of Water.

Table 2 shows the results obtained for the mass loss of jackfruit berries subjected to osmotic dehydration in sucrose solutions with concentrations of 40, 50 and 60 °Brix.

Table 2. Mean values of mass loss (MP) of jackfruit berries after the osmotic dehydration process at sucrose concentrations of 40, 50 and 60 °Brix

Sucrose solution	**Mass loss (g/100g)**
40 °Brix	27.87 ± 0.65c
50 °Brix	30.28 ± 0.74b
60 °Brix	32.71 ± 0.22a

Note: Different letters in the same column differ significantly by Tukey's test.

The mass loss of jackfruit berries after the osmotic dehydration process ranged from 27.87 g/100g to 32.71 g/100g. Statistically, these values were different from each other, when compared to the solids concentration in the osmotic solution.

Barros (2020) when applying the osmotic dehydration process in kiwi slices, I obtained water loss values ranging from 40.99 g/100 to 43.28 g/100g when solutions were used at concentrations of 40, 50 and 60 °Brix and dehydration temperatures of 40, 50 and 60°C.

Pessoa et al. (2016) when studying the kinetics of osmotic dehydration of Paluma guava, concluded that increasing the concentration of sucrose solution promoted a higher percentage of mass loss of guavas.

Table 3 presents the results obtained for the solid gain of jackfruit berries subjected to osmotic dehydration in sucrose solutions with concentrations of 40, 50 and 60 °Brix.

Table 3. Mean solids gain (DS) values of jackfruit berries after the osmotic dehydration process at sucrose concentrations of 40, 50 and 60 °Brix

Sucrose solution	Solid gain (g/100g)
40 °Brix	4.31 ± 0.25c
50 °Brix	6.81 ± 0.41b
60 °Brix	9.21 ± 0.19a

Note: Different letters in the same column differ significantly by Tukey's test.

The solids gain increased from 4.31 g/100g to 9.21 g/100g when the sucrose concentration was increased from 40 to 60°Brix. Statistically, the values were significantly different at the 5% probability level. According to Monteiro et al. (2020b) these results indicate that the high concentration of solids in the osmotic solution culminated in higher penetration rates of solids in jackfruit berries. After the osmotic dehydration process, the berries were submitted to drying kinetics at a temperature of 50°C, in which it was possible to calculate through Equation 5 the effective diffusivity values of the process.

Table 4 presents the effective diffusivity values and the coefficient of determination (R^2) for drying jackfruit berries first subjected to osmotic dehydration in sucrose solutions with concentrations of 40, 50 and 60 °Brix.

Table 4. Effective diffusivity of the drying process of jackfruit berries after the osmotic dehydration process at sucrose concentrations of 40, 50 and 60 °Brix

Conditions	Effective diffusivity (m^2 min^{-1})	R^2
40 °Brix	$(5.01 \pm 0.05)^a \times 10^{-8}$	0.9908
50 °Brix	$(3.38 \pm 0.11)^b \times 10^{-8}$	0.9936
60 °Brix	$(2.26 \pm 0.03)^c \times 10^{-8}$	0.9981

Note: Coefficient of determination (R^2); Different letters in the same column differ significantly by Tukey's test.

The fit of the Fick model to the experimental data showed a coefficient of determination greater than 0.99 (R^2>0.99) for all concentrations of the solutions. Diffusivity values ranged from $(2.26 \pm 0.03) \times 10^{-8}$ m^2 min^{-1} to $(5.01 \pm 0.05) \times 10^{-8}$ m^2 min^{-1} for concentrations of 60 and 40 °Brix, respectively. Statistically these calculated values were influenced by the concentration of the sucrose solution at the 5% level.

André (2019) in his studies to obtain raisin eggplants with flavor incorporation, the effective diffusivity ranged from 0.593 x 10^{-9} to 5.530x 10^{-9} m² s^{-1} for eggplants incorporated with 10% passion fruit and dried at 50°C and for eggplants incorporated with 5% fennel dried at 70°C, respectively.

Duarte et al. (2012) in their studies with jackfruit slices obtained a mean effective diffusivity of 0.973x10-8 m² s^{-1} for the treatment at 40 °Brix and 1.11x10^{-8} m² s^{-1} for 50 °Brix.

In Table 5, the values of water content of jackfruit berries in natura and after the convective drying process in their different conditions are presented.

Table 5. Water content of jackfruit berries in natura and after the process of osmotic dehydration combined with convective drying at a temperature of 50°C

Conditions	**Water content (g/100g)**
in natura	78.21 ± 0.14a
40 °Brix	20.16 ± 0.11d
50 °Brix	24.71 ± 0.09c
60 °Brix	27.19 ± 0.16b

Note: Different letters in the same column differ significantly by Tukey's test.

In natura jackfruit berries had a high water content 78.21 g/100g. The combined process of osmotic dehydration and convective drying reduced this content to 20.16 g/100g, 24.71 g/100g and 27.19 g/100g for berries previously immersed at 40, 50 and 60 °Brix, respectively. Statistically, the water contents were influenced by the sucrose concentration, in which, there was an increase in its values when there was an increase in its concentration from 40 to 60 °Brix.

Among the dehydrated berries that presented the highest water content, the one submitted to a solution of 60 °Brix, according to Barros (2020) this fact occurs due to the higher concentration of solutes in the product and during the drying process they form a surface layer which acts as a barrier to mass transfer in the product. Silva et al. (2017) in their studies with dehydrated bananas obtained a water content of 18 g/100g.

Table 6 shows the water activity values of jackfruit berries in natura and after the convective drying process in their different conditions.

Table 6. Water activity of jackfruit berries in natura and after the process of osmotic dehydration combined with convective drying at a temperature of 50°C

Conditions	Water activity
in natura	0.921 ± 0.01a
40 °Brix	0.416 ± 0.01c
50 °Brix	0.462 ± 0.02b
60 °Brix	0.490 ± 0.00b

Note: Different letters in the same column differ significantly by Tukey's test.

A water activity of 0.921 was observed for fresh jackfruit berries. Berries at 50 and 60 °Brix conditions did not present statistically significant differences when compared to each other. The behavior of the values of this parameter was related to the values obtained for the water content (Table 5). The samples submitted to the combined processes showed values lower than 0.5 ($aw<0.5$). Barros et al. (2019) stated that reduced values in relation to this parameter may represent greater stability during product storage, with foods with water activity above 0.60 being more susceptible to deterioration processes caused by molds, yeasts and biochemical reactions.

Table 7 shows the total soluble solids content of jackfruit berries in natura and after the convective drying process under different conditions.

Table 7. Total soluble solids of jackfruit berries in natura and after the process of osmotic dehydration combined with convective drying at a temperature of 50°C

Conditions	Total soluble solids (°Brix)
in natura	31.15 ± 0.10a
40 °Brix	49.14 ± 0.15d
50 °Brix	57.20 ± 0.05c
60 °Brix	69.50 ± 0.11b

Note: Different letters in the same column differ significantly by Tukey's test.

A significant increase in the total soluble solids content was observed when the sucrose concentration was increased. The values ranged from 49.14 to 69.50 °Brix. According to this increase, it occurs due to the incorporation of solids that occurs during osmotic dehydration and also due to the concentration (evaporation of water) during drying. Souza et al. (2011) when dehydrating jackfruit berries at 40 °Brix and drying at 60°C for 6 hours, obtained berries with a total soluble solids content of 61 °Brix.

Final remarks

Through the results obtained, it can be concluded that:

The application of the combined processes of osmotic dehydration and convective drying was feasible for jackfruit berries;

The increase in sucrose concentration promoted greater water and mass losses, and greater solids gain;

The drying process presented diffusivity ranging from (2.26 ± 0.03) x 10^{-8} m^2 min^{-1} for the treatment at 60 °Brix to (5.01 ± 0.05) x 10^{-8} m^2 min^{-1} for treatment at 40 °Brix;

The drying process showed significant reductions in water content and the berries showed a water activity below 0.5;

Finally, when there was an increase in sucrose concentration, greater was the incorporation of solids in jackfruit berries after convective drying.

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KINETIC MONITORING AND EFFECTIVE DIFFUSIVITY OF THE DRYING OF KALE STEMS

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro
Ana Carla Oliveira de Brito
Juliana Cruz Albuquerque
Fabrícia Santos Andrade
Maria Monique Tavares Saraiva
Aline Priscila de França Silva

Introduction

The consumption of vegetables is essential in any nutritionally adequate menu, due to their content of vitamins, minerals, fiber, low caloric intake and for increasing food residue in the gastrointestinal tract (TEIXEIRA et al., 2013). With the change in eating habits on the rise, vegetables have become one of the most consumed foods today, thus increasing production (PERREIRA et al., 2015).

Kale is one of the most popular vegetables in south-central Brazil, being produced in small areas in the green belts and also in home gardens, enriching the daily diet of the Brazilian population (MARCOLINI et al., 2008). Leaf kale is a typical autumn-winter brassica and has a certain heat tolerance and can be planted throughout the year. The adult plant emits numerous lateral shoots that can be used in its propagation (FILGUEIRA, 2003). Leafy cabbage (*Brassica oleracea* L.) is a vegetable that is very rich in nutrients, especially calcium, iron, vitamins A, C, K and B5. This vegetable is considered a good source of carotenoids, presenting, among vegetables, higher concentrations of lutein and beta carotene, reducing the risk of lung cancer and chronic eye diseases such as cataracts (LEFSRUD, 2007).

Fruit and vegetable residues are not part of the food menu of most populations, in addition to being discarded in large quantities by the food industries. Research reveals that plant residues are important sources of nutrients and could be used as an economic way to solve the problem of hunger and malnutrition in poor populations (SANTOS et al., 2003). Minimally processed food waste and fruit and vegetable waste used in the food industry are generally discarded and could be used as an alternative source of fiber (PEREIRA, et al., 2003). Obtaining these products is responsible for the production of significant amounts of vegetable stalks, which are eliminated during selection and cutting operations, and which constitute great waste for the industry (MAURO et al., 2010).

These stalks, specifically, have appreciable levels of dietary fiber, and their use in the preparation of processed foods will contribute to increasing the levels of insoluble fiber in the diet, in addition to reducing the growing accumulation of industrial waste (SÁNCHEZ & PÉREZ, 2001; PENNA & VILLAROEL, 2001). In this context, aiming at the reduction of by-products generated by the agroindustry, the present study aims to perform the drying kinetics of kale stems in an electric oven and adjust mathematical models (empirical and diffusive) to the experimental data.

Methodology

Cabbage leaves (*Brassica oleracea*) (Figure 1) were purchased at a local market in the city of Campina Grande, Paraíba, Brazil. Then they were transported to the laboratory, where the steps of cleaning, sanitization, sanitization in sodium hypochlorite solution (200 mg L^{-1} of free chlorine) were carried out for 15 min and washing in running water. With the aid of a domestic knife, their stems were removed and with a digital caliper they were cut in the shape of a cylinder with a radius (R=1.5mm).

Figure 1. Cabbage leaves and stalks before drying in an electric oven.

The kale stems (R=1.5mm) were evenly distributed in trays and the initial and equilibrium water content at each temperature was determined according to the methodology of Instituto Adolfo Lutz (BRASIL, 2008). Experimental data were expressed in terms of water content ratio (X^*), as described in Equation 1. The kinetics was performed at temperatures of 50, 70 and 90°C in an electric oven with a power of 1200 W.

$$X^*(t) = \frac{X(t) - X_{eq}}{X_i - X_{eq}} \qquad \text{(Eq.1)}$$

Where: X^*: water content ratio (dimensionless); X_{eq}: equilibrium water content (dry basis); X(t): water content (dry basis); X_i: initial water content (dry basis).

Three empirical functions *f* (t, a, b), Lewis (Equation 2), Handerson and Pabis (Equation 3) and Page (Equation 4) were fitted to the experimental datasets, using nonlinear regression through the Fitting Software. LAB Fit curves (SILVA & SILVA, 2008). The results of the empirical models were evaluated through the chi-square statistical indicators (χ^2) (Equation 5) and coefficient of determination (R^2).

$$X^* = e^{-at} \quad \text{(Eq.2)}$$

$$X^* = ae^{-bt} \quad \text{(Eq.3)}$$

$$X^* = e^{-at^b} \quad \text{(Eq.4)}$$

Where: X * is the admensional moisture ratio; a and b are the model parameters; t is the drying time.

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(X^*_{\exp,i} - X^*_{pre,i}\right)^2}{N-n} \quad \text{(Eq.5)}$$

Where: χ^2 is the chi-square function; $X^*_{\exp,i}$ is the experimental moisture ratio; $X^*_{pre,i}$ is the moisture ratio predicted by the model; N is the number of experimental data; and n is the number of model coefficients and constants.

Results

Table 1 shows the values obtained for each parameter of the mathematical models adjusted to the experimental data, as well as the statistical parameters: coefficient of determination (R²) and the chi-square function (χ^2).

Table 1. Parameters obtained by fitting the empirical models to the experimental data of the drying kinetics of cabbage stems in an electric oven

Model	T (°C)	Parameters A	Parameters B	R^2	χ^2
Lewis	50	(0.203 ± 0.007) x10^{-2}	-	0.985	0.028
	70	(0.438 ± 0.016) x10^{-2}	-	0.992	0.017
	90	(0.107 ± 0.038) x10^{-2}	-	0.989	0.014
Handerson and Pabis	50	1.020 ± 0.012	(0.211 ± 0.080) x10^{-2}	0.983	0.024
	70	1.033 ± 0.011	(0.468 ± 0.017) x10^{-2}	0.990	0.011
	90	0.979 ± 0.017	(0.102 ± 0.005) x10^{-1}	0.987	0.051
Page	50	(0.435 ± 0.011) x10^{-3}	1.262 ± 0.043	0.994	0.008
	70	(0.142 ± 0.017) x10^{-2}	1.223 ± 0.024	0.998	0.002
	90	(0.181 ± 0.024) x10^{-1}	0.874 ± 0.031	0.993	0.006

It was verified through Table 1, an increase in the values of parameter “a” and reduction of parameter “b” of the Page model when there was an increase in the drying temperature from 50 to 90°C. The Lewis and Handerson and Pabis models did not present correlations of their parameters with the temperature used in the process.

Among the evaluated models, the chi-square function (χ^2) varied between 0.011 and 0.051 for the other analyzed models, this value ranged between 0.002 and 0.008 for the Page model, under different experimental conditions. Regarding the values of the coefficient of determination (R^2), all adjusted models presented values greater than 98%, however, only the Page model presented values greater than 99% for the three temperatures studied. Thus, according to Santos et al. (2020), this behavior of low values of the chi-square function and high values of the coefficient of determination indicate a satisfactory fit of the mathematical model to the experimental data.

Souza et al. (2011) when performing the drying kinetics of forage radish at temperatures ranging from 30 to 70ºC, observed that the Midili model was the one that best fitted the experimental data. Garcia et al. (2019) when applying the drying process to lemongrass leaves at temperatures of 35, 45, 55 and 65°C, concluded that the Midili model was the one that best represented the process.

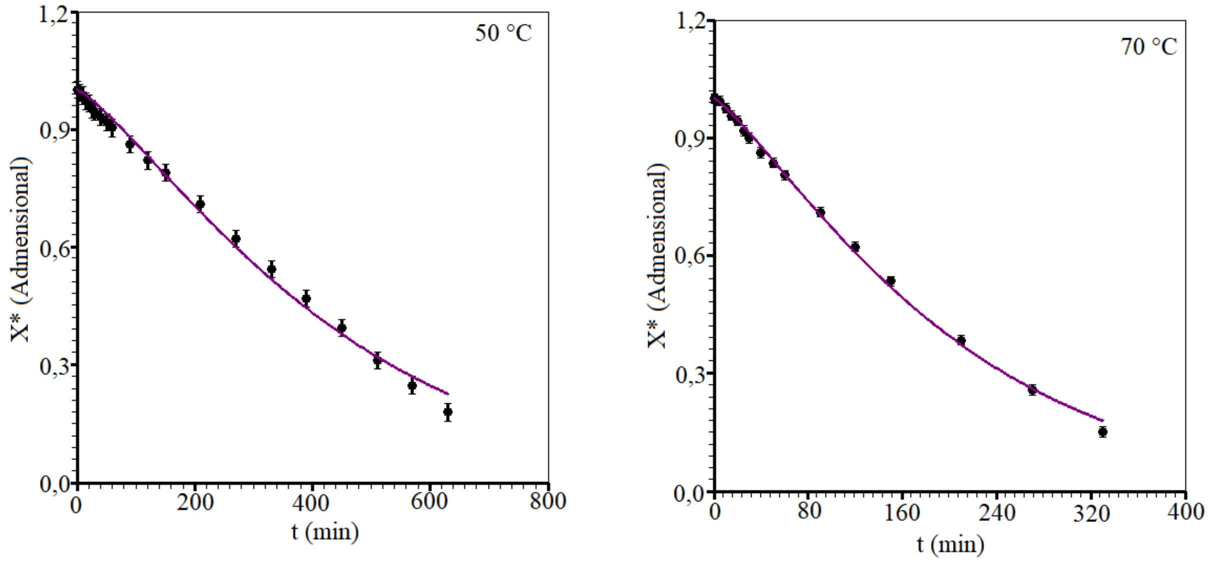
Table 2 shows the time taken for the drying process of the kale stems for each temperature used.

Table 2. Time of drying process of leaf cabbage stems in electric oven

Temperature (°C)	Drying time (min)
50	630
70	330
90	210

There was a noticeable reduction in the process time from 630 to 210 min when the temperature was increased from 50 to 90°C, which corresponds to 66.67% of the time. According to Oliveira et al. (2019) this knowledge helps in the development and improvement of dryers, enabling the calculation of the energy required during drying.

In Figure 2, the drying kinetics curves (ratio of moisture x drying time) of the leaf cabbage stems simulated by Page's empirical model for the three temperatures applied are presented.



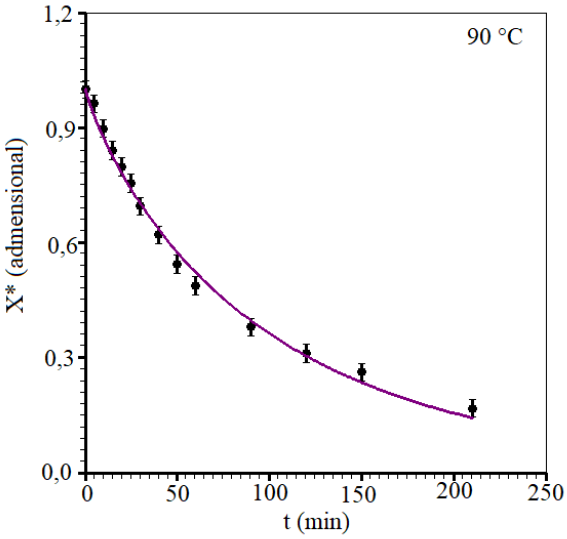


Figure 2. Simulated drying kinetics using Page's empirical model at temperatures of 50, 70 and 90°C.

It can be seen from Figure 2 that the first hours of drying were quite effective in reducing large amounts of water, so it can be seen that the curve reaches the most stable level of drying where the variation of the water withdrawn is minimal.

According to Almeida et al. (2020) the kinetics curves show that the increase in temperature favors mass transfer, reducing the dynamic equilibrium moisture and drying time, resulting in a higher rate of water removal, regardless of the type of material used.

Table 3 presents the results obtained by the analytical solution of the diffusion model with boundary condition of the first type and considering the geometry of an infinite cylinder.

Table 3. Results obtained by optimization using analytical solution

T (°C)	**D_{eff} (m^2 min^{-1})**	**R^2**	χ^2
50	3.720×10^{-10}	0.983	0.024
70	7.624×10^{-10}	0.978	0.097
90	2.107×10^{-9}	0.994	0.006

The fit of this model showed coefficients of determination (R^2) ranging from 97 to 99% and chi -square function values (χ^2) ranging from 0.006 to 0.097. The effective diffusivity values increased from 3,720 x 10^{-10} to 2,107 x 1^{-9} m^2 min^{-1} as the temperature increased from 50 to 90°C. Almeida et al. (2020) in their studies with melon seeds, also considered the geometry of an infinite cylinder and observed an increase in the diffusivity values when the drying temperature was increased.

Conclusion

Page's model was the one that best fitted the experimental data with a coefficient of determination R² above 0.99 and the lowest value of the chi-square function for all temperatures studied, mainly for 70ºC.

However, when analyzed the drying time at 90ºC showed a reduction of 36.36% in relation to 70ºC, resulting in greater effective diffusivity. It was observed that the first hours of drying were quite effective in reducing large amounts of water.

As a suggestion for future work, a physical, physical-chemical and technological characterization of the dehydrated material can be carried out and the influence of process temperatures on these parameters evaluated.

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PHYSICOCHEMICAL CHARACTERIZATION AND DETERMINATION OF THE SUGAR PROFILE BY HIGH PERFORMANCE LIQUID CHROMATOGRAPHY OF SAPODILLA PULP (MANILKARA SAPOTA L.)

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro
Ana Carla Oliveira de Brito
Juliana Cruz Albuquerque
Fabrícia Santos Andrade
Maria Monique Tavares Saraiva
Aline Priscila de França Silva

Introduction

Sapodilla is a succulent and very sweet fruit, its aroma can be easily identified. Sapodilla contains vitamins A, B1, B2, B5, and C. It still contains calories, carbohydrates, calcium, phosphorus and iron; the caloric value of sapodilla is 96 calories in every 100 g of the fruit (COSTA, 2000). It has a rounded shape, whose size varies from 3 to 10 cm in length. The evidence that the fruit is ripe is not linked to color, but rather to consistency, soft without being too soft. When ripe, the fruit has a slightly brownish, thin, but rough, inedible skin.

The edible part is a pulp that varies in color from yellow to brown. If the fruit is not quite ripe, ingesting the pulp may result in a small aftertaste in the mouth, due to the presence of traces of latex (EMBRAPA, 2016). It is a very perishable fruit and, as it is climacteric, its ripening under natural conditions is rapid, which makes its conservation and commercialization difficult (OLIVEIRA et al., 2011).

Despite having adapted to the most different soil, climate and altitude conditions in the tropics, its development and production are favored by high temperatures. Thus, in Brazil, the northeastern states stand out in the production of sapodilla. A great incentive for producers is the high price this fruit reaches in the domestic market. The ripe fruit has a good pulp yield, few seeds, a delicate flavor and a high content of soluble sugars (around 15-16º Brix) (COSTA et al., 2017; OLIVEIRA et al., 2011).

The pulp has been used in the gastronomic part in several countries, there is juice and ice cream that are produced from the fruit. Other products have been studied, mainly in India, however, in most cases, the processing leads to the loss of the characteristic flavor of the fruit (FREITAS SANTOS et al., 2020).

The search for diversification of sapodilla crops provided an increase in the interest in cultivation and consumption, and its commercialization was driven by the search for diversified products, where the aroma, flavor and nutritional value are valued. The use of fruits considered exotic reflects in the offer of new alternatives of fresh fruits for consumption and also as raw material for agroindustry (NASCIMENTO et al., 2008).

It is worth mentioning that the constituents of foods are directly related to their conservation, preparation of products and may vary according to the species and the soil and climatic conditions (GAVA et al., 2008; SOUSA et al., 2012).

High performance liquid chromatography (HPLC) is a process used in several classes of samples (organic and inorganic) identified as having high sensitivity and used in the analysis of separation and quantification of compounds. It is used for the simultaneous determination and combination of sugars, such as fructose, glucose and sucrose, with specific amperometric detectors for the separation of bound amino acids also pulsed (PAD evaporative light detector (ELSD) or refractive index detector (RID).

Therefore, the objective of this study was to evaluate the physicochemical characteristics and sugar profile of sapodilla pulp.

Methodology

The fruits of the sapota tree “sapoti” (*Manilkara sapota* L.) (Figure 1) were purchased at the open-air market in the city of Campina Grande – PB.

Figure 1. Fruit of the sapota tree “sapoti”.

Selection and cleaning of fruits

The fruits were selected manually, in order to eliminate the fruits at an advanced stage of maturation and with the presence of physical damage; then, the selected fruits were submitted to washing in running water and soon after, performed the sanitization, immersing them in a container containing sodium hypochlorite solution with a concentration of 200 ppm, for 15 min and finally rinsed in running water to remove excess hypochlorite solution.

Obtaining the pulp

After sanitization, the fruits were manually peeled and pulped, separating the peel, pulp and seeds fractions. The pulp was subjected to the characterizations described below.

Physicochemical characterization

The in natura sapodilla pulp was characterized, in triplicate, according to the following physicochemical parameters:

The water content was determined by drying the samples in an oven at 105°C until constant weight, according to the methodology described by the Instituto Adolfo Lutz (BRASIL, 2008);

The water activity (a_w) was determined using the Decagon® Aqualab CX-2T device at 25°C;

The pH was determined by direct reading on the digital pH meter (BRASIL, 2008);

The total titratable acidity (TTA) was determined by titration with sodium hydroxide (BRASIL, 2008);

Total soluble solids (SST) were determined by direct reading in a refractometer (BRASIL, 2008);

The ratio is the ratio between total soluble solids and total titratable acidity (SST/ATT) calculated according to Brasil (2008);

The ash content was determined by muffle incineration at 550°C (BRASIL, 2008);

The ascorbic acid (Vitamin C) content was determined by the *Tillmans* method. (BRASIL, 2008);

Total, reducing and non-reducing sugars were determined using the Lane and Eynon method (1934).

Determination of the sugar profile

The determination of the sugar profile was performed using a High Performance Liquid Chromatography (HPLC) system. The extract was obtained following the procedures described by Gao et al. (2012). The concentration of sugars was determined from standard curves (LEONEL et al., 2014).

Results

Table 1 shows the average values obtained for the physicochemical parameters of *in natura* sapodilla pulp.

Table 1. Physical-chemical characterization of *in natura* sapodilla pulp

Parameters	**Average ± standard deviation**
Water content (%)	76.21 ± 0.15
Water activity (a_w)	0.991 ± 0.01
pH	5.87 ± 0.02
Total titratable acidity (% de Citric acid)	0.22 ± 0.05
Total soluble solids (°Brix)	18 ± 0.00
Ratio (SST/ATT)	81.82 ± 0.05
Ashes (%)	0.41 ± 0.24
Vitamin C (mg/100g)	4.34 ± 0.16
Total sugars (% glucose)	12.38 ± 0.28
Reducing sugars (% glucose)	10.81 ± 0.36
Non-reducing sugars (% sucrose)	1.57 ± 0.14

The water content obtained was 76.21% and water activity of 0.991. Lower values were obtained by Ramos et al. (2020) when determining the water content in the pulp of umari (61,63%). According to Barros et al. (2019), fruits with high water content and water activity in food become more susceptible to the development of microorganisms and biochemical reactions responsible for their post-harvest degradation.

The observed pH value of sapodilla pulp (5.87) was lower than that found by Santos et al. (2020) when they also analyzed sapodilla pulp (6,65). Regarding the total titratable acidity, it appears that the value obtained (0.22%) of citric acid was lower than that observed by Silva et al. (2016) for a mixed blend of acerola and pineapple (0.73% citric acid).

Regarding the total soluble solids (TSS) content, sapodilla pulp presented a value of 18 °Brix. Oliveira et al. (2011) observed a total soluble solids content of 15.67 °Brix for *in natura* sapodilla pulp. According to Silva et al. (2020), the total soluble solids content is the main responsible for the flavor of the fruit and can be influenced by the conditions imposed during the production process, such as fertilization, temperature and availability of water and, mainly, by the genetic characteristics of the material.

In addition, this parameter represents one of the best ways to evaluate the degree of sweetness of the product, which is higher with the evolution of maturation, due to the processes of biosynthesis or even the degradation of polysaccharides. (CHITARRA & CHITARRA, 2005; RAMOS et al., 2013; BOTELHO et al., 2019).

The *ratio* parameter is calculated through the relationship between the total soluble solids content and the total titratable acidity of the product, the sapoti pulp *in natura* presented a *ratio* of 81.82, indicating a high degree of sweetness. According to Morgado et al. (2019) and Barros et al. (2020a), this parameter is able to indicate the degree of maturation of the fruit, as an increase in the degree of sweetness of the product is observed during the storage time.

The ash content obtained was 0.41%. Santos et al. (2020) determined the ash contents in pulps of fruits from the cerrado and obtained the following contents: 0.78% (butiti), 0.31% (cajá), 0.29% (murici) and 0.77% (tamarind). 4.34 mg/100g of ascorbic acid (vitamin C) were quantified in sapodilla pulp, higher values were obtained by Barros et al. (2020b) for achachairu pulp (9,61 mg/100g).

The levels of total, reducing and non-reducing sugars obtained in the present study were 12.38% glucose, 10.81% glucose and 1.57% sucrose, respectively. Values lower than those of the present study were obtained by Santos et al. (2020) when determining the sugar contents in sapodilla pulp, which obtained the following contents: 5.0% glucose (total sugars), 3.19% glucose (reducing sugars) and 1.81% sucrose (non-sugars) reducers).

According to Veloso et al. (2004) and Ribeiro et al. (2019) the main sugars in fruits are: glucose, fructose and sucrose in varying proportions, according to the species. Thus, in Table 2, the values obtained for the sugar profile of *in natura* sapodilla pulp are expressed.

Table 2. Sugar profile of *in natura* sapodilla pulp

Sugars	**Sapodilla pulp (g/100g)**
Maltose	0.017
Glucose	5.980
Fructose	4.850
Total	11.830

Through the analysis of the sugar profile, it can be observed that glucose had the highest content (5.98 g/100g) followed by fructose (4.85 g/100g) and maltose (0.017 g/100g). According to Bastos et al. (2016) fruit pulps had higher glucose and fructose content. Rocha and Uribe (2018) when determining the sugar profile of bananas at different stages of maturation obtained values ranging from 0.09 to 10.11 g/100 for glucose and from 0.07 to 9.23 g/100g for fructose.

Conclusion

The sapodilla pulp showed a higher percentage of *Ratio*, which indicates its high sweetness, among the sugar profile, the fruit presents glucose and fructose as the main parameters. The high water content and low acidity confirms its high perishability. According to all the physical-chemical characterization and the profile, the pulp can be used as raw material in sweet food formulations due to the sugar profile, which contributes to the industrial valorization of the fruit.

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INFLUENCE OF SONICATION TIME ON ULTRASOUND-ASSISTED EXTRACTION OF TOTAL PHENOLIC COMPOUNDS IN BLACK RICE GRAINS

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro
Ana Carla Oliveira de Brito
Juliana Cruz Albuquerque
Fabrícia Santos Andrade
Maria Monique Tavares Saraiva
Aline Priscila de França Silva

Introduction

Black rice, belonging to the species *Oryza sativa L*., stands out among the pigmented rice varieties for having good sensory characteristics and high nutritional value (ALENCAR et al., 2019). Black rice has high antioxidant activity. Phenolic acids, anthocyanins (cyanidin-3-glycoside (C3G) and peonidin-3-glycoside (P3G)) and proanthocyanidins are the main bioactive compounds that contribute to the antioxidant property of black rice. In addition, anthocyanins and phenolic acids have demonstrated antimicrobial properties in vitro (PROMMACHART et al., 2020).

Phenolic compounds play a vital role in human health and nutrition, preventing degenerative diseases, these compounds have more than 8,000 thousand chemical structures, being characterized according to their conformation of hydroxyl groups and links to aromatic rings, where phenols simple, phenolic acids and flavonoids due to their bioactive activities. These bioactive compounds are responsible for regulating the structural functions, growth and pigments of plants, helping to protect against the attack of various pathogens (GOMES et al., 2021).

Several techniques have been used in the literature to extract these compounds. However, conventional extraction techniques such as maceration and soxhlet are still commonly applied in the chemical, pharmaceutical and food industries to obtain various extracts. However, these techniques require long extraction periods, require a high energy cost and, in some cases, can degrade thermally sensitive substances (CARDOSO et al., 2020).

Ultrasound-assisted extraction has been highlighted, as it is a process intensification methodology, making it possible to obtain high extraction rates in shorter times. The cavitation generated by ultrasound is known to produce several effects on the matrix, such as: liquid circulation (solvent agitation) in the system and the generation of turbulence that can help increase mass transfer. Ultrasound-assisted extraction has numerous advantages, such as reduced extraction time, reduced solvent consumption, and extraction at lower temperatures can avoid thermal damage to the extract and minimize the loss of active compounds (SILVA et al., 2016).

In this context, the present study aims to perform ultrasound-assisted extraction kinetics of total phenolic compounds from black rice grains at different sonication times, adjust an empirical model to experimental data and finally determine its antioxidant activity.

Methodology

Feedstock

To carry out this study, grains of black rice (*Ozyra sativa* L.) (Figure 1) of the commercial brand Urbano® were used.

Figure 1. Grains of black rice (*Ozyra sativa* L.).

Extraction kinetics

Total phenolic compounds (CFT) extraction kinetics were performed for control grains and for ultrasound-assisted extractions at different sonication times: 10 min (US10), 20 min (US20) and 30 min (US30) with indirect contact at the frequency 40 kHz and 132 W power. For the assisted extraction procedure, extracts were prepared in the proportion of 10g of black rice to 100 mL of water, with 1 mL aliquots being withdrawn every 20 for 160 min.

Determination of total phenolic compounds (CFT)

The total phenolic compounds present in black rice grains were quantified using the Folin-Ciocalteau method described by Waterhouse (2006), using gallic acid as a standard. The calculations performed for the determination of phenolic compounds were based on a standard curve with gallic acid, and the readings performed in a spectrophotometer at 765 nm, with the results expressed in mg GAE/100g.

Empirical model adjustment

The results obtained for the extraction of total phenolic compounds (CFT) from black rice grains were adjusted using an empirical function f (t, a, b) with, at most, two adjustment parameters, being chosen the empirical equation obtained by the model of Peleg (Equation 1) and adjusted for growth curve.

$$f = \frac{x}{(a + b \times x)} \quad \text{(Eq.1)}$$

Where: f is the content of total phenolic compounds; a and b are model parameters and x is the extraction time.

The adjustment of the empirical equation to the experimental data was performed using the computer program *LAB Fit*, in addition to that, the coefficient of determination (R²) and the chi-square function (χ^2) were also evaluated.

Determination of antioxidant activity

After 160 min of extraction, the antioxidant activity was determined for each treatment. Antioxidant activity was performed by the DPPH• method according to the methodology described by Maria do Socorro et al. (2010) with adaptations. The final result was given in g sample/gDPPH• captured (EC50).

Statistical analysis

The results of antioxidant activity were submitted to statistical treatment by means of a completely randomized design with a test of comparison of means, using the software Assistet version 7.7 beta (SILVA & AZEVEDO, 2009).

Results

Table 1 shows the values obtained for the parameters of the Peleg model adjusted to the experimental data of the kinetics of extraction of total phenolic compounds from black rice grains at three different sonication times (10, 20 and 30 min).

Table 1. Peleg model parameters adjusted to experimental data of extraction of total phenolic compounds at three different sonication times

Conditions	**Parameters**	
	A	**B**
Control	0.1005	0.2456×10^{-2}
US10	0.0620	0.1917×10^{-2}
US20	0.0335	0.1705×10^{-2}
US30	0.0226	0.1467×10^{-2}

Note: US10: 10 min of sonication; US20: 20 min of sonication; US30: 30 min of sonication.

The parameter “a” showed a tendency to reduce its values from 0.1005 to 0.0226 when there was an increase of up to 30 min in the sonication time of the extraction process. This same behavior was observed for parameter “b” in which its values showed reductions from 0.002456 to 0.001467. This same behavior was also observed by Nunes (2019) in the kinetics of anthocyanin extraction from jambolan. It is worth noting that Peleg's model can be interpreted as an equation that results from the second-order concentration rate law, making it possible to give a physical meaning to the parameters obtained by curve fitting (TAO et al., 2014).

Table 2 shows the statistical parameters (R^2) coefficient of determination and (χ^2) chi-square function, obtained by fitting the Peleg model to the experimental data of extraction of total phenolic compounds at three different sonication times (10, 20 and 30 min).

Table 2. Statistical parameters obtained by fitting the Peleg model to the experimental data of extraction of total phenolic compounds at three different sonication times

Conditions	**R^2**	χ^2
Control	0.9814	0.1671×10^4
US10	0.9584	0.6660×10^4
US20	0.9846	0.3460×10^4
US30	0.9844	0.4961×10^4

Note: US10: 10 min of sonication; US20: 20 min of sonication; US30: 30 min of sonication; R^2 Coefficient of determination; χ^2 chi -square function.

The adjustment of the Peleg model showed coefficient of determination values greater than 0.95 (R^2>0.95). According to Carvalho (2021), these results may be due to the type of behavior, due to the non-linearity that occurred during the kinetics of the extractions. Regarding the chi-square function, high values in the order of 104 were observed. The high values of the chi-square function (χ^2) serve to quantitatively evaluate the relationship between the experimental data and the expected distribution, which justifies the high values found in the present study.

Figure 2 shows the adjustment of the Peleg model to the experimental data on the kinetics of extraction of total phenolic compounds from rice grains.

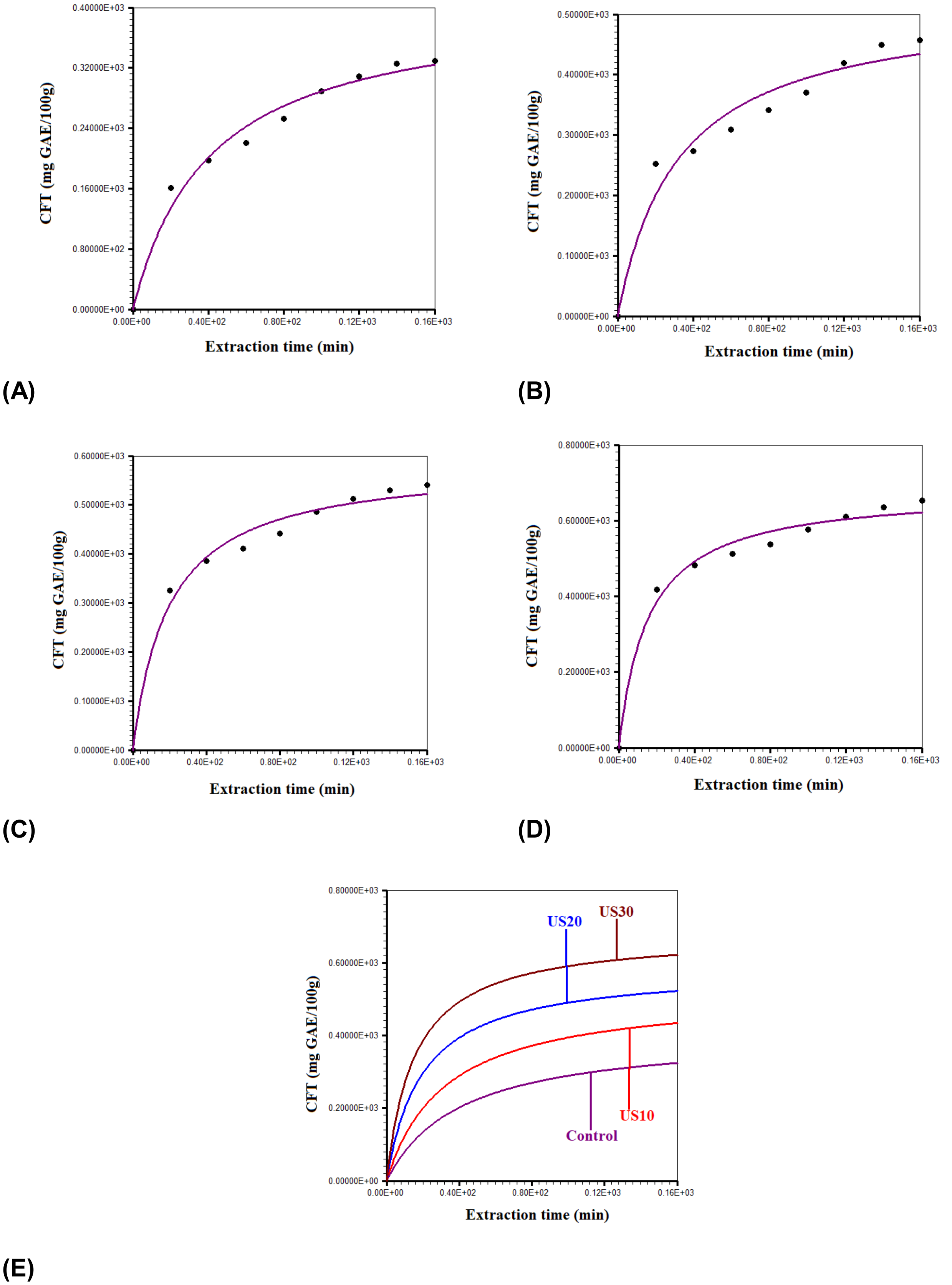

Figure 2. Kinetics of extraction of total phenolic compounds from rice grains, adjusted to the Peleg model under the following conditions: (A) Control, (B)US10, (C) US20, (D) US30 and (E) Superposition.

It can be seen through Figure 2 that higher concentrations of CFT were extracted at longer kinetic times (160 min) and longer sonication times (30 min). Statistically for all conditions when comparing the times of 140 and 160 min, the values obtained did not present statistically significant differences at the level of 5% of probability. The control condition presented 325.72 mg GAE/100g and 328.93 mg GAE/100g for the times of 140 and 160 min, respectively, and the condition of 30 min of sonication (US30) presented 652.31 mg GAE/100g and 635 99 mg GAE/100g for the times of 140 and 160 min, respectively.

According to Cardoso et al. (2020), this efficiency comes from the cavitation process that the ultrasonic waves produce, causing the formation of cavities, forming microbubbles that collide with solid surfaces and cause plant cells to be ruptured, facilitating the diffusion of the extracting solvent into the interior of the cell. headquarters.

Figure 3 shows the residual distribution of experimental error regarding the kinetics of extraction of total phenolic compounds from black rice grains.

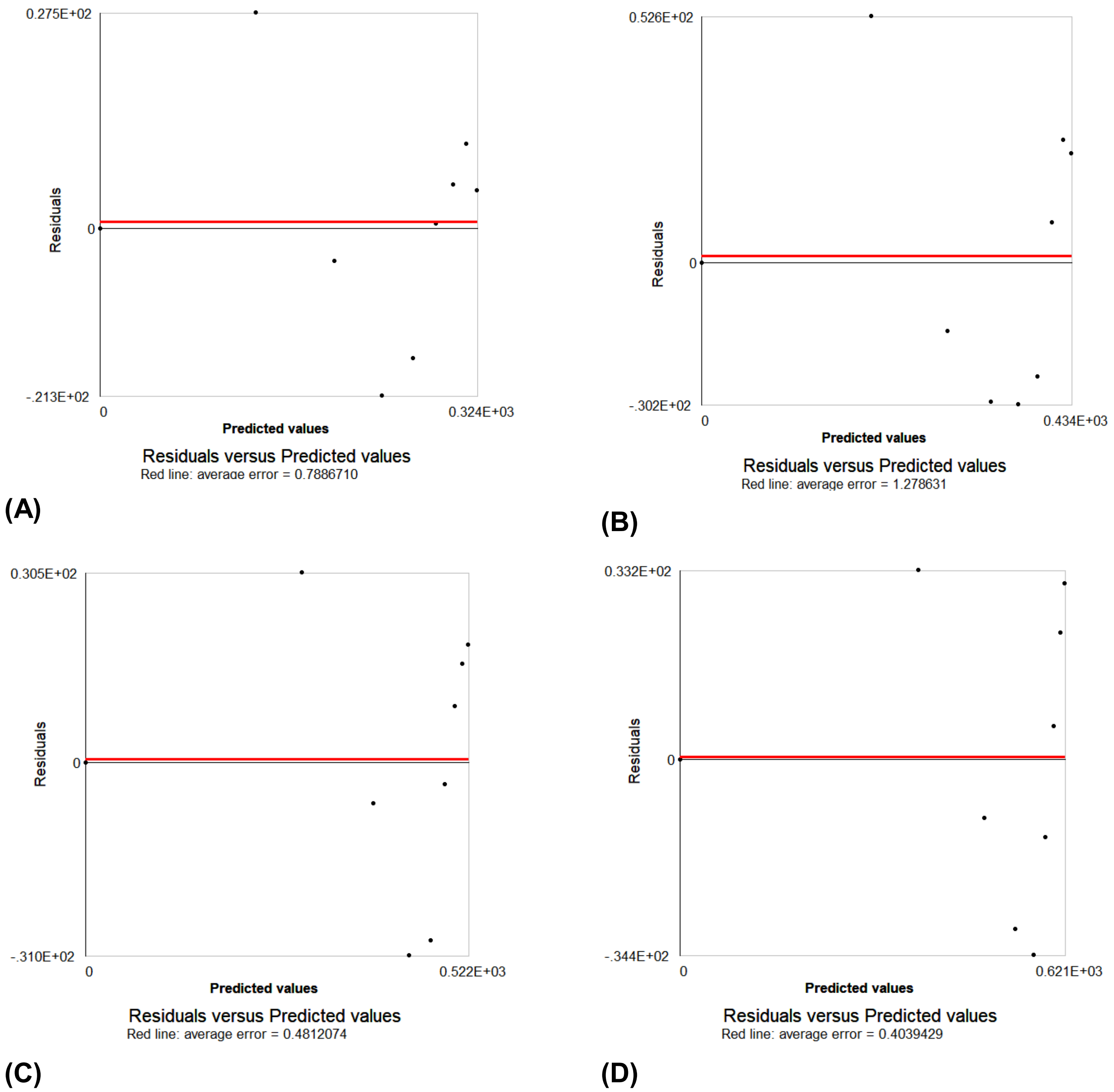

Figure 3. Distribution graphs (residuals versus predicted values) in the conditions of: (A) Control, (B) US10, (C) US20, (D) US30.

The solid line represents the mean error and its value for the extraction was 0.7886710 (control), 1.2788631 (US10), 0.4812074 (US20) and 0.4039249 (US30). The values obtained for the US20 (Figure 2C) and US30 (Figure 3D) experiments showed good agreement with the zero value. Table 3 shows the results obtained for antioxidant activity by capturing the DPPH• radical from black rice grains after 160 min of extraction under different conditions.

Table 3. Antioxidant activity by capturing the DPPH• radical from black rice grains after 160 min of extraction under different conditions

Conditions	**Antioxidant activity (g of sample/gDPPH•)**
Control	196.75 ± 2.01 ^{d}
US10	237.27 ± 1.66 ^{c}
US20	281.52 ± 3.54 ^{b}
US30	301.43 ± 4.39 ^{a}

Note: Means followed by the same letter in the same column do not differ from each other by *Tukey 's test* at the 5% probability level; US10: 10 min of sonication; US20: 20 min of sonication; US30: 30 min of sonication.

The values of antioxidant activity were higher when the longer sonication time was applied to the extracts. In comparison to the control grains, there was an increase of up to 104.68 g of sample/gDPPH• when the sonication time was increased by up to 30 min. Statistically this increase in mean values were significantly different when compared to each other.

It is observed that the sonication times that allowed extracting the highest content of total phenolic compounds also allowed the highest antioxidant potential. This same behavior was also observed by Cardoso et al. (2020) in studies with leaves and flowers of wild sage (*Hyptis Crenata Pohl Ex Benth*) and by Simões et al. (2013).

Conclusion

Based on the results obtained, it can be concluded that:

Ultrasound-assisted CFT extraction from black rice grains was efficient;

The extracts obtained by exposure to ultrasound for 30 min have a higher amount of CFT;

The time of 140 and 160 min showed no statistically significant difference at the 5% probability level;

The adjustment of the Peleg model showed coefficients of determination greater than 0.95 and chi-square values in the order of 104;

The antioxidant activity also showed higher values when the sonication time was increased.

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CONVECTIVE DRYING OF OKABO (ABELMOSCHUS ESCULENTUS): INFLUENCE OF PRE-TREATMENTS WITH ULTRASOUND AND ETHANOL

Virgínia Mirtes de Alcântara Silva
Victor Herbert de Alcântara Ribeiro
Ana Carla Oliveira de Brito
Juliana Cruz Albuquerque
Fabrícia Santos Andrade
Maria Monique Tavares Saraiva
Aline Priscila de França Silva

Introduction

Okra is a food of fundamental importance, having important nutritional components such as vitamins, minerals, soluble sugars, starch, fibers, hemicellulose and lignin. Although not a rich source of carbohydrates, the fresh fruit provides human nutrition with protein and vitamin A, B1 and C, as well as calcium and iron. In addition to pectin and lignin responsible for the viscous texture of the fruits. Immature okra is rich in flavonoid compounds that have antioxidant activity (SANTOS, 2018).

The culture of okra is carried out throughout the year, since Brazil has ideal climatic conditions for its cultivation, however, the northeast and southeast regions of the country stand out with higher production rates, being carried out mainly by family farming (COUTO & COQUERO, 2020).

Despite the numerous qualities previously reported, fresh okra has a high water content, which is one of the parameters responsible for the occurrence of deterioration reactions and development of microorganisms, resulting in a short shelf life. However, the feasibility of using the drying process as a conservation method, which consists of removing water from the product and aims to reduce losses related to the post-harvest stages, development of a product with greater added value and weight reduction and volume, implying less need for spaces for transport, storage and reduction of packaging costs (SANTOS et al., 2019).

Drying based on the use of hot air, is the most widely used method to preserve and obtain dry products, however, the high temperatures applied during drying can cause the degradation of the quality of the product. Even so, different emerging technologies or combined techniques are being used to improve and optimize these processes (HUANG et al., 2020).

Ultrasound has been extensively applied in various food processes, due to its potent attributes, which result in a remarkable enhancement of mass and heat transfer. The mechanical and cavitation effects of ultrasound are responsible for reducing the internal and external diffusion resistances of materials in the mass transfer during drying and, as a result, the drying rate can be improved, and as a consequence, the reduction of the drying time. drying, reducing energy expenditure (GUO et al., 2020; SANTOS et al., 2020).

The use of ethanol in drying, as a pre-treatment, either by insertion into the surface or as a component of a modified atmosphere, reduces the drying time, promotes the retention of volatile compounds and the preservation of the nutritional characteristics of foods (BRAGA et al., 2009).

Santos (2021), applied pre-treatments with ethanol and ethanol (Ethanol + US) in the convective drying of carrot cylinders, evaluating various parameters from micro and macrostructure, technological and nutritional quality, in addition to describing all the mechanisms involved. Noting that there were significant changes in consumption kinetics with processing time (~50%) and energy (42%). Increase of rehydration with initial rate and mainly of water higher than the control and carotenoids after drying were preserved in all treatments.

Similarly, Rojas et al. (2020) used ethanol pretreatments and ultrasound (Ethanol + US) in convective drying of pumpkin cylinders. Ethanol reduction and ultrasound showed effects on kinetics, a reduction in both consumption time (59%) and energy consumption (44%). The pre-treated ones preserved approximately 100% of the carotenoid content, while the sample showed partial degradation (23%) during drying. There was an increase in rehydration properties by 28% as well as in the amount of water.

Regarding mathematical modeling, it is one of the most relevant parameters for the efficiency of the drying process, as it is based on a set of mathematical equations used to characterize the physical phenomena that occur in the system, that is, to predict the time required for the drying process. reduction of the water content of the raw material under different drying conditions. Thus, the adjustment of the different mathematical models to the drying experimental data is essential to define the most appropriate mathematical model for each raw material.

In this context, in order to reduce post-harvest losses and optimize the drying process for different food matrices, the present study aims to apply isolated and combined ultrasound (USM) and ethanol (ETL) pre-treatments in okra slices, in addition, another objective of this study is to perform the drying kinetics of okra slices and apply an empirical mathematical model to describe the process.

Methodology

Feedstock

To carry out this study, okra (*Abelmoschus esculentus*) (Figure 1) acquired in the local market was used. After selection, cleaning and sanitization, the okra were cut into 3 mm slices with the aid of a domestic knife and a digital caliper.

Figure 1. Whole okra and slices.

Pre-treatments with ultrasound and ethanol

The okra slices were subjected to pretreatments of ultrasound (USM), immersion in ethanol (ETL) and the combination of samples (USM+ETL). For all pre-treatments, okra slices were immersed in absolute ethanol (99.5%, for 10 min, kept at 30°C, in a sample/solution ratio of 1:4 (m/m). For the samples submitted to ultrasound, the recipients were placed in an ultrasonic bath with a frequency of 25 kHz, intensity of 4870 W m^{-2}.

Drying kinetics

The drying of the control, USM, ETL and USM+ETL samples was performed at a temperature of 70°C in an air circulation oven with a fixed air velocity of 2.0 m s^{-1}. Moisture loss was recorded using a digital scale with a precision of 0.001g. The drying process was continued until the constant mass reading was recorded.

The moisture ratio of the drying process was calculated according to Equation 1.

$$X^*(t) = \frac{X(t) - X_{eq}}{X_i - X_{eq}} \qquad \text{(Eq.1)}$$

Where, X^* is the moisture ratio (dimensionless), X_{eq} is the equilibrium moisture content (dry basis), X(t) is the actual moisture content of the sample at the moment t (dry basis) and X_i is the initial moisture content (dry basis).

Empirical model adjustment

The adjustment of Page's empirical equation (Equation 2) to the experimental data was performed using the computer program LAB Fit, and the coefficient of determination (R²) and the chi-square function (χ^2) were also evaluated.

$$X^* = \frac{X(t) - X_{eq}}{X_i - X_{eq}} = \exp(-at^b) \quad \text{(Eq.2)}$$

Results

Figure 2 shows experimental data on drying kinetics of control and pre-treated okra slices (USM, ETL and USM+ETL), expressed as the ratio of water content as a function of drying time.

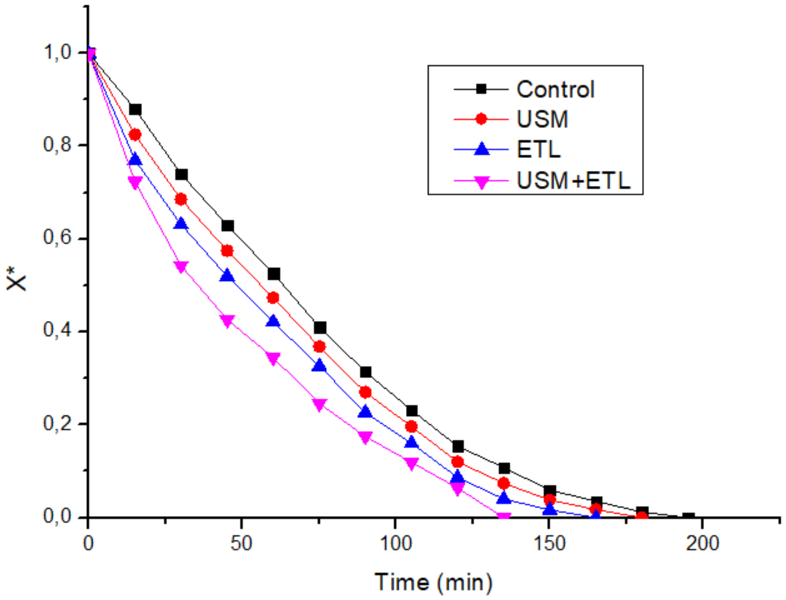

Figure 2. Moisture ratio versus drying time of drying kinetics of okra slices under different conditions: control, ultrasound (USM), ethanol (ETL) and ultrasound + ethanol (USM+ ETL).

It is observed that the loss of water is more accentuated at the beginning of the drying process, reducing this rate over time. It is also noted that the pre-treatments applied directly influenced the total drying time, in which the okra pre-treated with a combination of ultrasound and ethanol (USM+ETL) required a shorter time interval (135 min) to reach the content of balance water.

It can also be observed that the pre-treatments applied promoted an increase in the rates of removal of water from the product and a decrease in the drying time for the okra slices to reach equilibrium, when compared to the control slices that were not applied any pre-treatment. (195 min).

Table 1 shows the values of parameter “a” obtained by fitting Page's model to the experimental data set of drying kinetics of okra slices. The Page model was chosen to represent the phenomenon investigated in the present study, due to its simplicity and low number of parameters.

Table 1. Parameter “a” obtained by fitting Page's model to experimental data of drying kinetics of okra slices under different conditions

Conditions	**a**
Control	0.2017×10^{-2}
USM	0.4008×10^{-2}
ETL	0.7488×10^{-2}
USM+ETL	0.1028×10^{-1}

Note: Ultrasound (USM), ethanol (ETL) and ultrasound + ethanol (USM+ ETL).

It can be seen from Table 1 that the values of parameter “a” increased as the slices were submitted to pre-treatments, with values ranging from 0.002017 to 0.01028. This same behavior was also observed by Santos et al. (2020) when drying guava slices pre-treated with ultrasound. Correa et al. (2010) stated that the parameter a of the Page model tends to increase when there are higher drying rates, reaching the equilibrium water content in a shorter time of exposure of the product to the drying air, thus evidencing that the process of the slices pre-treated with USM+ETL occurred with a higher drying rate.

In Figure 3, it is possible to visualize the values obtained for the parameter of “b” of the Page model.

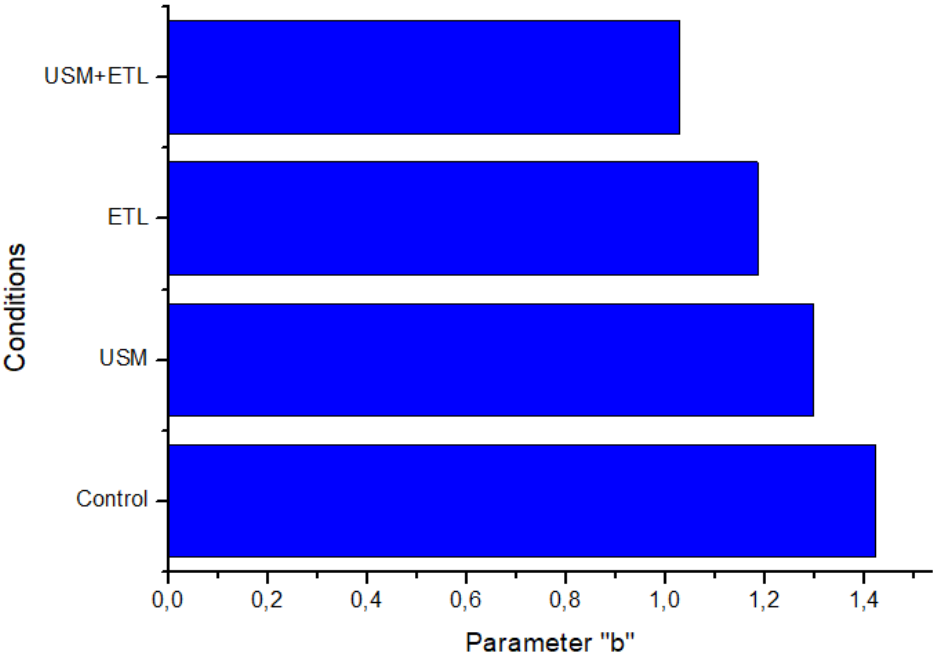

Figure 3. Parameter “b” obtained by fitting Page's model to experimental data of drying kinetics of okra slices under different conditions: control, ultrasound (USM), ethanol (ETL) and ultrasound + ethanol (USM+ ETL).

The values of parameter “b” were 1.4235 (control), 1.298 (USM), 1.1862 (ETL) and 1.0284 (USM+ETL). A similar behavior was observed for the parameter “a” (Table 1), in which the values showed reductions as the okra slices received pre-treatments.

Table 2 shows the statistical parameter values obtained by fitting Page's model to the experimental data set of the drying kinetics of okra slices.

Table 2. Statistical parameters obtained by fitting Page's model to experimental data of drying kinetics of okra slices under different conditions

Conditions	**R^2**	χ^2
Control	0.9966	0.5669×10^{-2}
USM	0.9933	0.9588×10^{-2}
ETL	0.9892	0.1358×10^{-1}
USM+ETL	0.9913	0.8179×10^{-2}

Note: Ultrasound (USM), ethanol (ETL) and ultrasound + ethanol (USM+ ETL); Coefficient of determination (R^2); Chi -square function (χ^2).

In reference to the values of the coefficients of determination (R^2), values greater than 0.99 (R^2>0.99) were obtained, except for the slices submitted to pre-treatment with ethanol, which showed a value of 0.9892 (0.98< R^2<0.99). The chi-square function values were in the order of 10^{-2} and 10^{-1}, showing a good fit of the model to the experimental data.

Figure 4 shows the experimental curves of drying kinetics of okra under different conditions (control, ultrasound (USM), ethanol (ETL) and ultrasound + ethanol (USM+ ETL)), adjusted with the Page model, which was the chosen to be fitted to the experimental data.

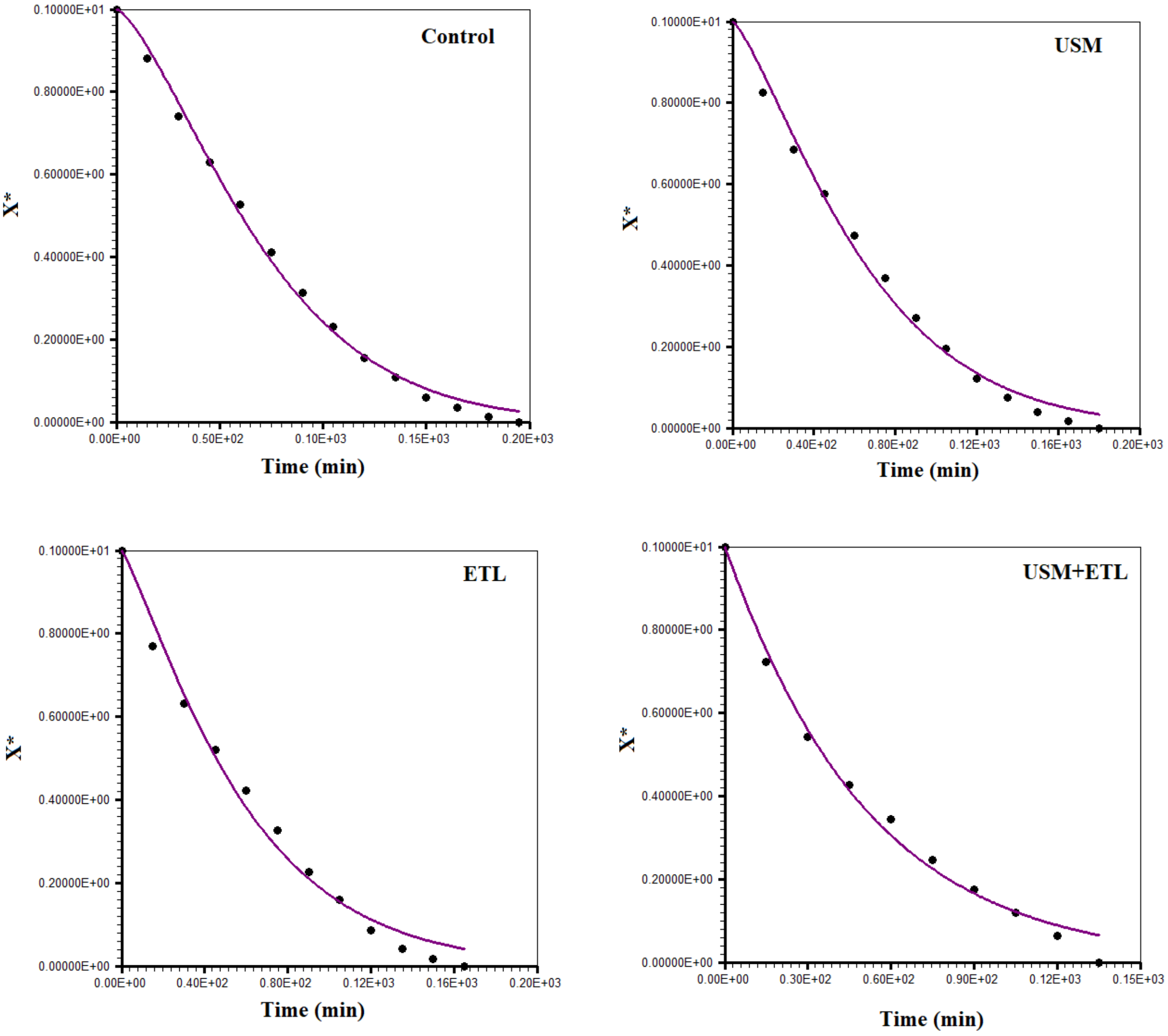

Figure 4. Adjustment of Page's model to experimental data of drying kinetics of okra slices under different conditions: control, ultrasound (USM), ethanol (ETL) and ultrasound + ethanol (USM+ ETL).

The drying curves were influenced by the pre-treatment applied, with a gradual reduction in drying times being observed. It was verified that the experimental points were very close to the predicted curves, explained by the high values of the coefficient of determination and low values of the chi-square function for the model selected in the prediction of the drying curves.

Conclusion

Based on the results obtained, it can be concluded that:

The application of ultrasound and ethanol pre-treatments was efficient in reducing the drying time of the process;

Page's model satisfactorily described the phenomenon of the drying process;

The parameters of the Page model were significantly reduced with the application of pre-treatments;

The combination of pre-treatments (USM+ETL) is the most suitable for drying okra slices, as it presented higher drying rates.

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Curriculum

Aline Priscila de França Silva: *Graduated in Licentiate in Chemistry from the Federal University of Campina Grande, Center for Education and Health. Currently a Master's student in Agricultural Engineering from the Federal University of Campina Grande. She participated in scientific initiation projects focused on the area of food chemistry. She has experience in drying and semi-solid fermentation. Master's student in Agricultural Engineering at UFCG.*
alinepriscila33@gmail.com

Ana Carla Oliveira de Brito: *Student of the Degree in Chemistry at the State University of Paraíba, she holds a degree in Industrial Chemistry from the State University of Paraíba (2017), a master's degree in Chemistry, with an emphasis in the area of Analytical Chemistry, from the State University of Paraíba (2019), using the Near infrared (NIR) spectroscopy technique associated with chemometrics we analyzed the formation of aggregates in the clay-polyphosphate system. During graduation, he developed activities involving inorganic chemistry in research with the themes: Synthesis and Characterization of regional clay minerals for application in the photodegradation of organic contaminants (2014/2015); Characterization and application of montmorillonites enriched with iron (II) and iron (III) in adsorption of textile dyes (2015/2016) all these researches by the Institutional Research Initiation Scholarship Program (PIBIC); Monitoring of the discipline Functions of Several Variables (2014); Monitor in the discipline Analytical Chemistry Exp; I; 2015. Volunteer student at the Nucleus for Research and Extension in Food (NUPEA), for a supervised internship, where she worked in the microbiological analysis of the jambolan milk drink (Syzygium cumini); 2017, Also developed activities in the Pedagogical Residency program (2018/2019).*
aninhabrito24@gmail.com

Fabrícia Santos Andrade: *Graduated in Industrial Chemistry from the State University of Paraíba (2020), she worked in the Institutional Program of Scientific Initiation Scholarships in the area of Agricultural Sciences and Food Technology from 2016 to 2020, working in the area of processing and reuse of agricultural waste with experience in the areas of osmotic dehydration, drying by the oven method, processing of pulp into powder by layer of foam and food storage. She is currently a Master's student of the Graduate Program in Agricultural Engineering at the Federal University of Campina Grande in the area of Processing and Storage of Agricultural Products.*
fabricia.santos.andrade@hotmail.com

Juliana Cruz Albuquerque: *She has experience in the field of Chemical Engineering, with an emphasis on Characteristic Operations of Biochemical Processes. In research in the areas of Environmental Engineering: Conducting a study on the drying kinetics of coffee grounds in an oven with air circulation for subsequent oil extraction, developing an analysis of the research data using a 2^3 factorial design. Drying of Fruits by the Foam-Mat Process. - Considering that, among the processes for obtaining powdered fruits, the Foam Mat is a relatively simple drying process, the general objective of this project was to study the drying of tropical fruit pulps using this technology. In the Agricultural Sciences Area: Elaboration of Probiotic Milky Dessert added with Jabuticaba Jelly-Evaluating the elaborate dairy products from jabuticaba*

(Myrciaria cauliflora) with probiotic potential- Evaluating the stability of the probiotic flan produced with the jabuticaba peel jelly. She is currently a master's student at the Graduate Program in Agricultural Engineering at the Federal University of Campina Grande with a concentration in processing and storage of agricultural products.
julianalbuquerquepb@hotmail.com

Maria Monique Tavares Saraiva: *Agronomist from the Federal Rural University of Pernambuco - UFRPE/UAST, in which she acquired experience in the area of environmental education and aptitude for the development of studies on ecological restoration, based on work carried out in the area of conservation and sustainable use of Caatinga biodiversity. . She was a CNPq Scientific Initiation Scholar for two years (2016-2018) and a volunteer monitor of the Rural Economy discipline (2016-2018). He holds a master's degree in Agro-Food Technology from the Federal University of Paraíba (UFPB - CCHSA), which has developed research on the quality of raw materials with an approach aimed at sustainable exploitation and physical, chemical and physical-chemical characterization of native fruits. She is currently a doctoral student in the Agricultural Engineering program at the Federal University of Campina Grande (UFCG), focusing on the research line of processing and storage of agricultural products.*
moniquetavaresaraiva@gmail.com

Victor Herbert de Alcântara Ribeiro*: Graduated in Agroecology from the State University of Paraíba (2016). Master in Agricultural Sciences (Agroecology) by the Center for Human, Social and Agrarian Sciences of the Federal University of Paraíba - Campus III, Bananeiras. Doctoral candidate in Engineering and Natural Resources Management with emphasis in the area of Heat and Mass Transfer linked to Food Refrigeration and Drying (drying, osmotic dehydration, lyophilization, food enrichment and new products (development of food for fish with mesquite residues Prosopis)) juliflora (Sw) DC) also works with topics related to biofertilizers, organomineral substances and sesame (Sesamum indicum L.). Doctoral Student of the Postgraduate Program in Engineering and Natural Resources Management at the Federal University of Campina Grande, UFCG / CTRN / Campus Campina Grande-PB.*
victor_herbert_cg@hotmail.com

Virgínia Mirtes de Alcântara Silva*: Graduated in Biological Sciences at the University of Vale do Acaraú-CE in 2010, Doctor and Master in Natural Resources Engineering at the Federal University of Campina Grande - UFCG, Specialist in Geoenvironment and Semi-arid Water Resources at the Federal University of Campina Large - UFCG. State University of Paraíba - UEPB, Specialist in Geography and Environmental Management by the Integrated University of Patos - FIP. Working in the areas of Remote Sensing and GIS, Desertification, Ecological Restoration, Recovery of Degraded Areas and Climatological Characteristics of Brazil, Extreme Rain Events and Environmental Disasters. Doctor in Natural Resources Engineering working in the area of Cryoconservation of Plant Genetic Resources with Peanut, Wedge and Sorghum Seeds. Currently works with related research in the area of Heat and Mass Transfer related to Refrigeration and Drying of Foods (drying, osmotic dehydration, lyophilization, food enrichment and new products). She is part of the editorial board of the EPTEC publisher. Reviewer of the African Journal of Plant Sciences; African Journal of Food Science; Journal of Agricultural Economics and Development, Journal of Plant Breeding and Crop Science, Journal of Horticulture and Forestry (JHF), Journal of International Pharmaceutical Research,*

Journal of Medicinal Plant Research, and African Journal of Agricultural Research. Member of the São Paulo Association of Rural Extension - APAER / SP. Member of the International Research Network for the Development of Climate Resilience - RIPEDRC- Climate Resilience Network, created in 2019, in an international partnership, approved by CNPQ / Araucária Foundation notice: PI 06/2018 Researcher Links Program (United Kingdom), which provided for the organization of the "Brazil-United Kingdom Workshop on Financing for Climate-Resilient Urban Development", held from 9-13 September 2019.

virginia.mirtes2015@gmail.com; virginia.m.alcantara@gmail.com

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