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Production of Concentrated Red Pitaya (*Hylocereus Undatus*) Juice by Vacuum Evaporation

Produção de Suco Concentrado de Pitaya Vermelha (*Hylocereus Undatus*) por Evaporação sob Vácuo

Producción de Jugo Concentrado de Pitaya Roja (*Hylocereus Undatus*) por Evaporación al Vacío

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Abstract
The processes of concentration of liquid food, especially fruit juices, are complex processes that can cause changes in physical, biochemical, and sensory properties. The main objectives of juice concentration are to increase the product's shelf life and biochemical and microbiological stability and reduce the volume, which leads to lower transport and storage costs. Processes using heat for conservation and concentration continue to be the most used by the food industry. However, heat treatments have as their main disadvantage their negative impact on the retention of nutritional and quality factors, such as colour, aroma and flavour. There are many scientific, technological, and food engineering efforts to ensure greater yield, better retention of compounds and lower processing costs. New processes and technologies have been studied for the concentration of juices. The evaporation experiments were carried out to characterize the raw material used and the final product obtained. The concentration by evaporation was carried out using a vacuum evaporator. In the industry, multi-effect evaporators are usually used to circumvent the problem of the boiling point increase caused by the solvent's partial evaporation in each effect. Therefore, since the experiments were carried out using only a single-output pump, some adaptations were necessary regarding the actual process conditions and the objectives of the evaporation experiment. The process was conducted in two stages: (1) study and industrial use of the national red pitaya; (2) concentration of the juice under vacuum and the characterization of the product obtained.
Keywords: Dragon fruit; Concentrated juice; Vacuum evaporation.

Resumo
Os processos de concentração de alimentos líquidos, principalmente sucos de frutas, são processos complexos que podem causar alterações nas propriedades físicas, bioquímicas e sensoriais. Os principais objetivos da concentração do suco são aumentar a vida de prateleira e estabilidade bioquímica e microbiológica do produto e reduzir o volume, o que leva a menores custos de transporte e armazenamento. Os processos que utilizam calor para conservação e concentração continuam sendo os mais utilizados pela indústria alimentícia. No entanto, os tratamentos térmicos têm como principal desvantagem o impacto negativo na retenção de fatores nutricionais e de qualidade, como cor, aroma e sabor. Existem muitos esforços científicos, tecnológicos e de engenharia de alimentos para garantir maior rendimento, melhor retenção de compostos e menores custos de processamento. Novos processos e tecnologias têm sido estudados para a concentração de sucos. Os experimentos de evaporação foram realizados para caracterizar a matéria-prima utilizada e o produto final obtido. A concentração por evaporação foi realizada usando um evaporador a vácuo. Na indústria, evaporadores multiefeitos são normalmente utilizados para contornar o problema do aumento do ponto de ebulição causado pela evaporação parcial do solvente em cada efeito. Portanto, como os experimentos foram realizados utilizando apenas uma bomba de saída única, algumas adaptações foram necessárias em relação às condições reais do processo e aos objetivos do experimento de evaporação. O processo foi conduzido em duas etapas:

(1) estudo e aproveitamento industrial da pitaya vermelha nacional; (2) concentração do caldo sob vácuo e caracterização do produto obtido.
Palavras-chave: Fruta do dragão; Suco concentrado; Evaporação a vácuo.

Resumen
Los procesos de concentración de alimentos líquidos, especialmente los jugos de frutas, son procesos complejos que pueden provocar cambios en las propiedades físicas, bioquímicas y sensoriales. Los objetivos principales de la concentración de jugo son aumentar la vida útil y la estabilidad bioquímica y microbiológica del producto y reducir el volumen, lo que conduce a menores costos de transporte y almacenamiento. Los procesos que utilizan calor para la conservación y concentración siguen siendo los más utilizados por la indústria alimentaria. Sin embargo, los tratamientos térmicos tienen como principal desventaja su impacto negativo en la retención de factores nutricionales y de calidad, tales como color, aroma y sabor. Hay muchos esfuerzos científicos, tecnológicos y de ingeniería de alimentos para garantizar un mayor rendimiento, una mejor retención de compuestos y menores costos de procesamiento. Se han estudiado nuevos procesos y tecnologías para la concentración de jugos. Los experimentos de evaporación se realizaron para caracterizar la materia prima utilizada y el producto final obtenido. La concentración por evaporación se llevó a cabo utilizando un evaporador al vacío. En la industria se suelen utilizar evaporadores multiefecto para evitar el problema del aumento del punto de ebullición que provoca la evaporación parcial del disolvente en cada efecto. Por lo tanto, dado que los experimentos se realizaron utilizando solo una bomba de salida única, fueron necesarias algunas adaptaciones con respecto a las condiciones reales del proceso y los objetivos del experimento de evaporación. El proceso se realizó en dos etapas: (1) estudio y aprovechamiento industrial de la pitaya roja nacional; (2) concentración del jugo al vacío y caracterización del producto obtenido.
Palabras clave: Dragon de fruta; Jugo concentrado; Evaporación al vacío.

1. Introduction

Pitayas or pitahayas are scaly fruits due to the size of the bracts of the bark that resembles dragon scales. They are reddish-pink or white fruits produced by several species of cacti, especially Steno cereus quadriparesis, plants native to Mexico. Such fruits have a juicy pulp, full of tiny seeds and are consumed naturally or used in preserves, ice cream, or drinks (IFIS, 2009). Its seeds contain a mild and laxative oil that strongly affects total cholesterol and low-density cholesterol levels in humans. Pitaya oil contains high levels of functional lipids and can be an essential oil source. In terms of comparison, pitaya oil has similar characteristics to linseed and canola oils, which allows its use in natural dye production processes in the food industry (Borges, 1998).

In Angola, specifically in the province of Luanda, more than 310 tons of pitayas are produced annually, of which a significant portion degrades due to poor disposal and storage. These phenomena are also registered in Benguela and Bengo provinces. However, pitaya is an exotic fruit whose use has been intensified in recent times in the world due to its intrinsic nutritional value. The pitaya, rich in fibers, water, calcium, iron, phosphorus, and vitamins B, C, and E, has reduced calorie content. Among its benefits for the human organism are the protection of the body cells, improvement in the functioning of the intestine and aid in weight reduction, when present in a healthy and balanced diet (Quiroz et al, 2018).

The most appreciated effect of pitaya comes from its iron content. This chemical element reduces tiredness and fatigue and contributes to the normal formation of red blood cells and hemoglobin. These are essential for the human body's oxygen transport and contribute to the normal functioning of the body's defense. For these reasons, the consumption of dragon fruit juice has increased in the diet. The physical and chemical characteristics of the fruits define their commercial value, such as the visual appearance of the fruits, the soluble solids, the acidity, the sugars and the organic acids of the pulp, which, in combination, result in the characteristic flavour of the fruit. According to Reis et al. (2021), the determination of soluble solids is one of the aspects explored in the in natura consumption of the fruit, resulting in the respective industrial processing.

According to studies by Hoa et al. (2006), variations in the physicochemical characteristics of dragon fruit after harvesting showed that the marketing time of these fruits, without any chemical or physical treatment, is approximately 10 days.

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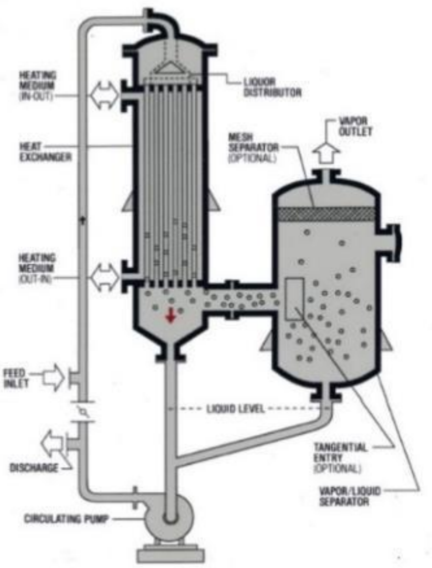
From a nutritional point of view, dragon fruits do not have different contents than other fruits, mainly tropical fruits. However, it stands out for its taste and pulp texture, mainly due to significant amounts of seeds, as Arivalagan et al. (2021) stated. The Author compares the characteristics of this fruit with those of kiwi in terms of the content of seeds of the two fruits.

These characteristics make it possible to maximize the use of the potential of products extracted from pitaya and other fruits, as they provide significant improvements in human health, conditions that inspire the development of the agro-industrial sector. For this, the processing of agricultural products must guarantee adequate storage for a more extended period to better use the nutritional characteristics and guarantee commercialization.

According to data from the FAO, the World Bank and the Natural Resources Institute of Great Britain, in 2011, food waste in sub-Saharan Africa represented an estimated volume of resources of US$ 4 billion per year, which could have been used to feed, approximately 48 million people (FAO, 2013). This waste results from the limited technical and technological expertise during harvesting, processing, transport and storage processes due to the lack of adequate infrastructure for processing.

In this regard, scientific and technological studies have been carried out to propose the resolution of the problems herein mentioned, mainly in the context of the production of concentrated juices, which provide an increase in shelf life, as the implementation of the process avoids microbiological degradation, facilitates storage and overcomes seasonal limitations. In this case, several technologies are used to concentrate juices, especially vacuum evaporation and membrane separation, which have been preferred for preserving the nutritional character of fruit juice (Mushtaq, 2018).

Figure 1 - Rising film evaporator used for the production of concentrated juice.



Source: Authors.

Evaporation using vacuum consists of removing water existing in the interstices of fresh foods, based on mass heat and movement principles, to obtain a product with reduced water concentration.

For Ordonez (2005), the evaporation operations used in the juice production sector aim to increase the concentration of total solids to reduce water activity, constituting an operational strategy for food preservation. This operation can be used as a step before other unit operations, emphasizing dehydration, crystallization, and sterilization and operations that focus on reducing food mass and volume and transport, storage, and distribution costs.

In this way, evaporators, characterized as equipment used in the food industry to carry out evaporation, increase concentration and separation based on the thermodynamic principles of phase equilibrium. The falling film evaporators are among the most appropriate equipment, with a short residence time and high heat transfer coefficients. These types of equipment perform better when used in heat-sensitive food concentration processes and do not tolerate high temperatures (Chawankul et al., 2001, Bertoli et al., 2017, Muachia et al., 2020).

Fruit juices are available in virtually all markets in the world, whether from a single fruit species or blends, with reduced water concentration, cloudy, pulpy, processed and stabilized with the implementation of appropriate heat treatment that involves the implementation of processes with high pressures, packaged, refrigerated and marketed (Mihalev et al, 2018).

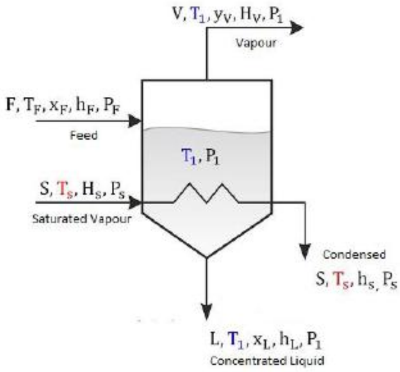
Therefore, the food industry represents an essential link between the agricultural sector and the final consumer. Implementing evaporation, sterilization, freezing and drying operations minimizes losses during storage, conditions that guarantee uniformity in the supply and development of new products. For this reason, the use of technologies in manufacturing processes prospects the achievement of high production capacities, which should meet the population's needs, especially with the high growth rates observed in recent times. In this case, vacuum evaporation takes place in a single operation commonly used in the food industry for the concentration of fruit and vegetable juices, the evaporation of milk, and the manufacture of sugar and syrups (Donaldio, 2009).

The evaporator provides heat to evaporate water from the food by a thermal exchange associated with mass transfer through phase changes in equilibrium stages. In order to minimize the thermal degradation of food due to the loss of aroma, colour and nutritional ingredients, evaporation must be carried out when steaming occurs at low temperatures. In this case, three factors are involved, as described (Roger & Evangelista, 1985):

I. With the decrease in water fractions, the viscosity of the juice increases up to the maximum limit of thermal exchange;
II. According to Antoine's equation, the product temperature is closely related to the system's internal pressure. In this case, the pressure imposed on the system limits the maximum operating temperature up to the condition that guarantees maximum elimination of the water in the juice;
III. The greater the internal vacuum in the evaporator, the greater the thermal exchange in the juice, a condition that limits thermal degradation and loss of flavour, aroma, colour and nutrients.

Global mass balances for a single-effect evaporator involve a series of mathematical equations that describe the loss of water mass over time and the consequent increase in viscosity of the mass accumulated in the equipment. This description can be applied to the process of concentration of pitaya juice, which involves a continuous evaporator with the insertion of the juice in the evaporator, the heating and consequent removal of the vapours formed by condensation and the progressive addition of the mass of the in natura juice at lower rates that the recovery rate of the vapours formed and the removal of the base products, in smaller proportions than the in natura juice feed, according to Figure 2.

Figure 2 - Currents involved in the vacuum evaporation operation.



Source: Authors.

In this way, the global mass balance involved in this system can be described based on Equation 1.

$$\dot{m}_F - \dot{m}_V - \dot{m}_L = 0 \tag{1}$$

Equation 2 presents the mass balance per component, considering that the feed is made with a given concentration of water and the steam and liquid streams leave the system with different water concentrations, that is, a higher concentration of water in the steam and lower concentration of this chemical species in the liquid stream, already in the concentrated juice condition, according to Equation 2.

$$\dot{m_F} x_F - \dot{m_V} y_v - \dot{m_L} x_L = 0 \tag{2}$$

The energy balance in the evaporation path is described by Equation 3, as a function of the latent heat of phase change. The heating energy up to the phase change temperature must be incorporated into this equation.

$$\dot{Q} = \dot{m_V} H_v + \dot{m_L} h_L - m_F h_F = \dot{m_s} \lambda_s \tag{3}$$

Thus, the total energy consumption in the process must involve the heating heat and the phase change, represented by the latent heat, according to Equation 4.

$$Q = m_F C_{PF}(T - T_F) + m_s \lambda_s \tag{4}$$

If the possibility of observing the input mass is greater than the total mass in the evaporator output streams, the mass balance must involve the transient process that encompasses the accumulation term, according to Equation 5.

$$\dot{m_F} x_F - \dot{m_V} y_v - \dot{m_L} x_L = \frac{dm}{dt} \tag{5}$$

When evaporation is carried out in batches, the process does not involve feed streams but an initially fed load that must be evaporated over time, resulting in the accumulation of concentrated juice, up to commercialization conditions, according to Equation 6.

$$m_v y_v = \frac{dm}{dt} \tag{6}$$

In this context, based on the descriptions above, this paper is the result of the development of studies to concentrated pitaya juice to increase the product's shelf life and biochemical and microbiological stability and reduce the volume, which leads to lower transport and storage costs.

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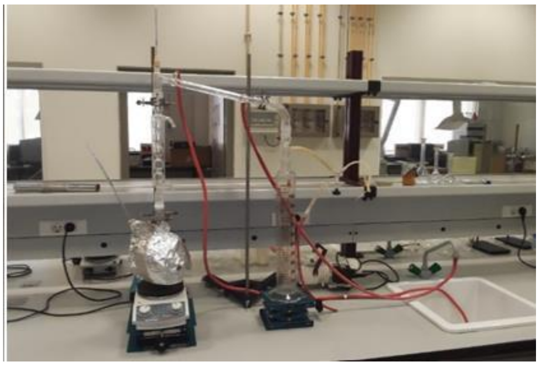
2. Methodology

2.1 Equipment e Materials

For the development of this work, glassware was used, emphasizing the vacuum system, distillation flask and condensers, among others. The materials thus referenced were structured to compose the experimental apparatus shown in Figure 3.

Figure 3 - Experimental apparatus used to produce concentrated pitaya juice.



Source: Authors.

The determination of the system's internal pressure was made using the equation proposed by Antoine (Equation 7), which correlates the system's temperature with the saturation pressure. For this case, the reading of the system's temperature in the operating conditions makes it possible to determine the saturation pressure and, consequently, the power of the pump used to carry out these tests.

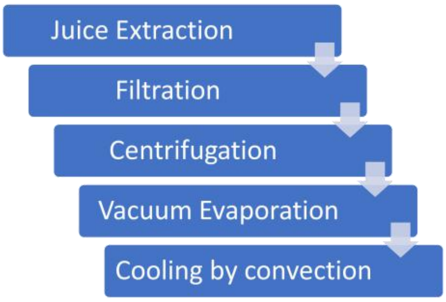
$$LnP^{Sat}{}_{/KPa} = A - \frac{B}{t^{\circ}C + C} \quad (7)$$

Where A, B and C are tableted constants referred for each chemical specie.

2.2 Experimental Procedures

The execution of the experimental tests followed the procedures described in Figure 4.

Figure 4 - Sequence of operations used for juice concentration.



Source: Authors.

Initially, pitaya fruits were purchased, essentially red fruits obtained on the national market. Then, the fruits were opened and the juice was extracted, which was later characterized in terms of viscosity, specific mass, dissolved sugar content and total solids.

The extracted juice was inserted into three volumetric flasks with two outlet nozzles and respective volumes of 230 ml, 230 ml, and 250 ml. Thus, three experimental tests of pitaya juice concentration were carried out using the experimental apparatus described in Figure 3.

The experimental tests consisted of inserting the natural juice into the volumetric flask and starting heating with the action of a thermal plate supported by a magnetic stirrer initially inserted in the volumetric flask. The heating dynamics were rigorously monitored until reaching the steady state, establishing the vapor phase formation that rises towards the top of this apparatus and is recovered as a liquid after condensation.

The performance of the process was evaluated as a function of the accumulation of condensate arising from the evaporation of the juice contained in the flask as a function of time, whose final test result is characterized by the stability of the volume over time. Furthermore, the temperature evolution over time was recorded as removing water increases the concentration of total solids in the juice, increasing the mixture's temperature. In general, each experimental test was carried out for more than one hour, with strict control of pressure, temperature and the accumulation of recovered water.

After the completion of each test, the juice remaining in the flask was cooled by natural convection and the juice and water masses were weighed, whose data were used to close the mass balances of the process. Finally, the concentrated juice was packaged using glass packaging and conserved in environments with reduced temperatures (refrigerator).

The concentrated juice was characterized by the measurement of color, odor, density, kinematic viscosity, pH, Brix and refractive index.

a) Refractive index

An Abbe-type refractometer was used to determine the refractive index. To read the refractive index of the juice, the equipment was first calibrated and two drops of liquid were inserted into the refraction prism. The scale was then read in the refractometer eyepiece. After calibration with acetone, the refractometer was cleaned with cotton. With this same procedure, the refractive index of juice was measured, with the insertion of two drops of juice sample in the prism of the refractometer, followed by the reading in the visual field.

b) Density

The density of the juice produced was determined by measuring the volume and respective mass. In this case, the mass of the beaker was initially determined and, consequently, the mass of the juice was inserted into the beaker up to 10 ml and weighed at room temperature. Using Equation 7, the specific mass of juice produced was determined.

$$\rho = \frac{m' - m}{V} \qquad (8)$$

Where m’ is the mass (g) of the cylinder with juice (g), m is the mass (g) of the empty cylinder and V is the volume (ml) of juice.

c) Kinematic viscosity

The kinematic viscosity was obtained using an Ostwald viscometer based on the ABNT NBR 10441 methodology.

d) pH

Water proof pH meter Model HI9124 was used to determine pH. The pH electrode was inserted into a clean beaker containing each of the juice samples before (Kays, 1999; Safdar, 1999).

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e) Brix

To use the refractometer prism to mensure the Brix, this equiment wasa calibrate with air and pure water. Follwing, was drop the sample using a dropper to ensure ample coverage of the refractometer prism and measure the Brix.

The results from those procedure were compared with several concentrated juices marketed in Angola, whose physicochemical characteristics are on the respective labels.

3. Results and Discussions

The juice extraction process explored in this study 4 (four) samples of red dragon fruit, having initially observed the size, in terms of average diameter, length and respective masses, according to the data in Table 1.

Table 1 - Parameters of 4 national red pitaya samples.

Sample	Shape	Diameter (cm)	Length (cm)	Fruit Weight (g)	Bark weight (g)
1	Ovulate	9.75	10.00	490.605	125.425
2	Globular	8.90	9.70	450.075	125.425
3	Globular	8.30	11.70	440.070	127.360
4	Ovulate	8.60	9.70	393.580	109.085
Total Valour		35.55	41.10	1.774.330	487.295
Average Value		8.89	10.28	443.583	121.824

Source: Created by the Author (2021).

The data in Table 1 show that the pitaya samples studied in this work have an average diameter of 8.89 cm, an average length of 10.28 cm., a weight of 443.583 grams and an average residual mass of 121.824 grams, corresponding to 27.75%. In this vein, studies by Esquivel et al. (2007) and Duda-Chodak (2010) showed that the average pitaya length is 8.5 cm and 7.3 cm in diameter, respectively, values similar to the pitaya sample used in these studies.

The pulp mass obtained after removing the peel and consequent juice extraction was 120.888 grams of seeds and 1,166.147 grams of natural pitaya juice. The physical-chemical characterization was performed with the juice produced when the parameters in Table 2 were determined.

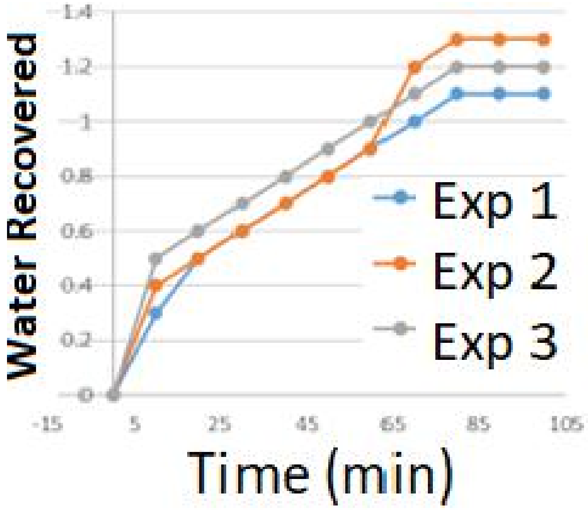
Table 2 - Physical-chemical parameters of natural dragon fruit juice.

Parameter	Extracted Juice
Specific mass (g/ml)	1,0156
º Brix	13,0
Temperature (ºC)	28,8
Refractive index	1,3525
Bx-TC	13,6
pH	4,55
Conductivity (mS/cm)	5,76
SDT (ppt)	2,823
Salinity (psu)	3,175
Resistivity (Ω/m)	173,6

Source: Created by the Author (2021).

The juice characteristics shown in Table 2 were essential for measuring the performance of the evaporation process based on the elimination of water in the initial juice sample. Evaporation under vacuum to produce concentrated pitaya juice was carefully carried out with the recovery of vaporized water, whose data are shown in Figure 5, for the three tests carried out.

Figure 5 - Evolution of the juice concentration process.



Source: Authors.

Figure 5 shows the accumulation of vaporized and condensed water initially present in pitaya juice, as a function of time, for the three tests. It is observed that the most significant effect of vaporization occurs in the first 80 minutes when water recovery reaches levels of 98%. After this phase, the stability of the volume of recovered water is registered, characteristic of the partial elimination of water in the juice under the operating conditions used. Changing or increasing these conditions is possible only when changing the operating parameters, which may result in increased vacuum in the systems, resulting in increased evaporation rates.

The remaining products from the experimental tests, concentrated juice and condensed water, are shown in Figure 6, which shows the volume of water recovered for the mass of juice initially inserted in the distillation flask under vacuum.

Figure 6 - Visual characteristics of vacuum evaporation products.

Source: Authors.

The concentrated juice was characterized and the data were compared with the data initially determined for the fresh juice when observing the performance of the evaporation process, which guarantees substantial changes in the physical parameters evaluated, as shown in Table 3.

Table 3 - Physical-chemical parameters of concentrated red pitaya juice.

Parameter	Fresh Juice	Experiment 1	Experiment 2	Experiment 3
Specific mass (g/ml)	1,0156	1,025	1,025	0,9984
ºBrix	13	14,8	17,2	14,7
Temperature (ºC)	28,8	29,9	30,8	30,1
Refraction Index	1,3525	1,3553	1,3592	1,355
Bx-TC	13,6	16,7	18,0	15,5
pH	4,55	4,5	4,53	4,56
Conductivity	5,76	6,283	7,675	7,327
SDT (ppt)	2,823	3,079	3,761	3,591
Salinity (psu)	3,175	3,468	4,297	4,089
Resistivity (Ω/cm)	173,6	159,2	130,3	136,5

Source: Authors (2023).

The data analysis in Table 3 shows that the implementation of the experimental tests carried out in this study provided changes in the physical characteristics of the samples submitted to the vacuum evaporation processes, guaranteeing the production of concentrated juice with similar characteristics to those commercialized juices. In comparative terms, one can observe the increase in specific mass, ºBrix, Bx-TC, thermal conductivity, total dissolved solids content and salinity, all associated with the elimination of water in the initial sample, which results in an increase in the concentration of dissolved solids and which results in an increase in the content of the referenced parameters.

The analysis of the mass balances involved in the process shows that in the vacuum evaporation tests, 70% of the water was removed from the mass initially inserted in the flask, which represents a performance of 87%. The three experiments carried out showed similar performance. In their context, it is possible to close the mass balance based on the sum of the inlet and outlet mass flows based on the mass initially inserted in the vacuum distillation flask. However, reduced losses were observed, representing 1% of the mass initially inserted in the flask, probably due to phenomena associated with surface tension on the walls of the equipment.

The losses in the system are due to the equipment present in the experimental apparatus that contained leaks in the coupled hoses, reduced resistance due to the action of the vacuum pump, in addition to the deficiency in the vacuum regulating valve. This condition limited the total use of the vacuum produced.

4. Conclusions

Based on the results presented in this work, it can be concluded that:

i. Implementing vacuum systems makes it possible to produce concentrated juice as a technological alternative for agroindustry development in Angola, enhancing the conservation and durability of food.

ii. With the elimination of water, the juice produced allows for greater stability and intensifies the colour and odor, ensuring an increase in the drink's taste.

iii. The mass balances involved in the process were consistent, with reduced losses resulting from the interconnections established for the maintenance of the system.

iv. When characterized, the juice produced presents similar results to the literature used to support the development of this work.

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