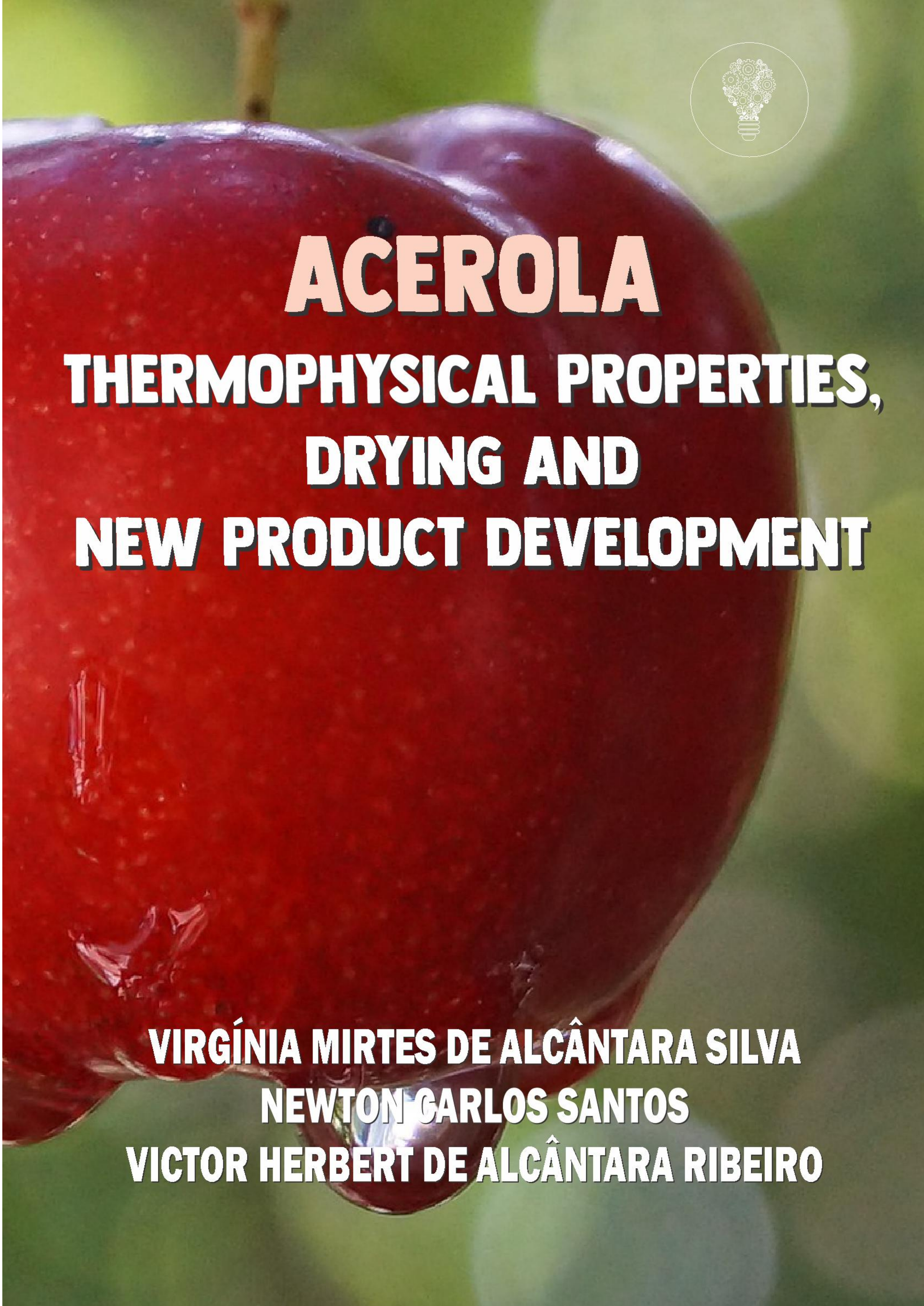

ACEROLA

THERMOPHYSICAL PROPERTIES, DRYING AND NEW PRODUCT DEVELOPMENT

VIRGÍNIA MIRTES DE ALCÂNTARA SILVA
NEWTON CARLOS SANTOS
VICTOR HERBERT DE ALCÂNTARA RIBEIRO

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A173 Acerola thermophysical properties, drying and new product development/Silva et al.

— Campina Grande: EPTEC, 2021.
102 f.: il. color.

ISBN: 978-65-00-33220-9

1. Super fruit. 2. Industry. 3. New products. 4. Ascorbic acid. 5. Fruit pulp. I. Silva, Virgínia Mirtes de Alcântara. II. Santos, Newton Carlos. III. Ribeiro, Victor Herbert de Alcântara. IV. Título.

CDU 62

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Eptec editora portal tecnológico
1.a Edição
Campina Grande-PB
2021

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Acknowledgements

We would like to thank the Federal University of Rio Grande do Norte - Graduate and the Chemical Engineering Program for their unconditional support to our research. The Engineering Unit of the Federal University of Campina Grande for the use of the laboratories and providing all the equipment to carry out this work. Our special thanks to Professor Renato de Arruda Veiga for his guidance throughout the work and for choosing the strategic raw material "the acerola" for the development of all this research. To the National Council for Scientific and Technological Development (CNPq) and to the Coordination for the Improvement of Higher Education Personnel (CAPES) for master's and doctoral scholarships for authors.

The organizers

Presentation

With a territorial extension of 8,512,965 km^2, Brazil dedicates to preservation in 66.3% of its territory, on the other hand it uses only 7.8% of its territory to feed billions of people in the world (MIRANDA, 2018). Part of this comes from about 44 million tons of tropical, subtropical and temperate climate fruits, enabling the trade of native and exotic species during all seasons of the year (IBRAF, 2018).

The great diversity of fruit trees in Brazil may be due to its six large biomes (Amazon, Cerrado, Caatinga, Atlantic Forest, Pantanal and Pampa, which places it prominently as the most mega-diverse country in the world, whether alongside 16 others countries, as mentioned by Mcneely et al. (1990), or alongside 11 countries as proposed by Mittermeier et al. (1997), however, it is necessary to revere, in addition to the native species, the exotic fruit trees introduced and acclimated to our Parents.

Fruit trees, in general, have great nutritional importance for people of all countries, not only because of their fresh consumption, but also because of their wide applicability in the development of new products obtained from their processing. Thus, they represent a socially fundamental raw material for their qualities such as the high content of antioxidant micronutrients (ascorbic acid, carotenoids, minerals and polyphenols, natural pigments, aromatic substances, in addition to a wide variability of biomolecules - L-ascorbic acid, gallic acid , rutin, and anthocyanins) with potential application in the food and pharmaceutical industry (MELLO, SOMACAL & EMANUELLI, 2018).

The high amounts of fruit by-products, such as peel, pulp and seeds, represent a natural source of nutrients and biocompounds that can be effectively used as functional food ingredients. In addition, dietary fiber stands out due to its relevance in regulating the intestine, preventing cancer, diabetes and cardiovascular diseases (MACAGNAN, 2013).

The phytochemicals present in fruit trees play important roles in the body, preventing various diseases, as they exert antioxidant, anti-inflammatory, anti-obesity, anti-diabetic, anti-microbial, anti-cancer, cardiovascular, hepatoprotective actions, etc. (BERNARDI et al., 2019)

Brazil produces and processes an impressive amount of native fruits, such as: Pineapple, Cabeludinha, Cocoa, Chestnut, Cashew, Cupuaçu, Grumixama, Goiabinha-serrana, Jabuticaba, Passionfruit, Pitanga, Uvalha (VAVILOV, 1992), etc. It still produces numerous exotics such as: Avocado, Banana, Persimmon, Orange, Lemon, Apple, Mango, Papaya, Watermelon, Melon, Peach, Kiwi, Grape, among others.

Its processing is one of the most strategic steps, as the immense distances in the country, between the production areas and the main urban areas, make it impossible to load in view of its perishability due to its physical-chemical characteristics. Thus, this activity is vital for marketing and consumption, preserving its nutritional properties without the need to add preservatives or dyes (OLIVEIRA & SANTOS, 2015).

However, in processing, the high water activity causes its perishability, as the availability of water in fruits is responsible for microbiological, chemical and enzymatic reactions. Thus, heat treatments are necessary to reduce the amount of pathogenic and/or deteriorating microorganisms, inactivate enzymes, delay metabolic processes while preserving the nutritional characteristics of each specific product. Temperature is another relevant parameter, affecting the preservation of micronutrients - especially vitamins - since any change directly affects the characteristics of the desired product, modifying the physical, chemical and biochemical characteristics according to the composition of each fruit species (AZEVEDO, 2018).

Thus, it is up to the culture researcher to carry out a detailed analysis, among the range of parameters available, in order to apply the appropriate techniques for obtaining and developing pulps, jellies, cookies, ice cream, yogurts, etc. In this context, for the experimental design, it is necessary to determine its physicochemical complexity (density, specific heat, conductivity and thermal diffusivity). Therefore, there are different equations to predict thermophysical properties and modeling, among other parameters that will serve to determine the design of industrial equipment, in addition to the analysis and control of processes (heat transfer, both at high and low temperatures).

In view of this, the development of new products derived from strategic fruit trees, such as the delicious acerola, strategically chosen for this work, is fundamental for the innovation and development of new products (cookies, jellies, yogurt, ice cream, etc.) as described below in each chapter of this relevant work.

In the present case, the fruit is an acerola (*Malpighia emarginata* DC), a shrubby fruit tree of the Malpighiaceae family, native to Central America, which arrived in Brazil in the 1950s, but obtained only in the 1990s (BATISTA et al., 1991) , it is also commonly known as Cherry from the Antilles, Cherry from Barbados, and Semeruco (LEÓN, 1987).

It is a plant whose size can reach three meters in height, whose branch arises from its trunk, from a base, forming a dense crown, with tiny leaves of a dark-bright green hue. Its flowers are pinkish-white, arranged in bunches that flower all year round, bearing fruit after three or four weeks. When ripe, its fruits have a color that varies from orange to wine, as a result of anthocyanins, especially pelargonidin and malvidin (APTA, 2007). Its surface is smooth or divided into three sections with one seed each. The fruit's flavor is slightly acidic and the aroma is reminiscent of grapes.

One of the most relevant characteristics of the fruit, which can be consumed fresh (sweeter cultivars) or for industry (as cv. More acidic) is that it has a high concentration of vitamin C (overcoming orange and lemon), and also contains provitamin A, and vitamins B1 and B2, in addition to calcium and iron. It also has phytonutrients, in addition to anthocyanins, such as carotenoids, phenolics and flavonoids. Regarding the extract, many studies have shown that the antioxidant of acerola extract was much higher compared to extracts rich in polyphenols from other fruits, such as açaí, cherry, mango, strawberry and grape (CHANG et al., 2019).

Therefore, an acerola is a strategic food matrix for the development of sustainable agriculture in several regions of the country. The Northeast of Brazil stands out in the production of tropical and temperate fruits, among them the acerola has stood out as a strategic raw material for the base of new products, with high production in the Northeast (64% of the national production), highlighting Bahia, Ceará, Paraíba, Pernambuco and Sergipe (IBGE, 2019; EMBRAPA, 2017).

Acerola production is very relevant for Brazil, with more than 60 thousand tons of this fruit, positioning us as the world's largest producer. The State of Pernambuco is the largest producer, with 21,351 tons produced, followed by Ceará, with 7,578 tons, and in third place Sergipe, with 5,427 tons of fruit produced (IBGE, 2017). Exports mainly go to Europe, the United States, Japan, China and India.

Finally, I believe in this work because it represents the continuous effort of a relevant research team whose goal is the dissemination of strategic research, publicly and free of charge, to various scientific areas, including agricultural engineering, especially the food of its peoples, as well as nutrition of the people of other nations.

Dr. Renato Ferraz de Arruda Veiga

Diretor Administrativo da Fundação de Apoio à Pesquisa Científica – FUNDAG

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Preface

The work *THERMOPHYSICAL PROPERTIES OF ACEROLA, DRYING AND DEVELOPMENT OF NEW PRODUCTS*, materializes the synergistic effort of our team of researchers aligned with the goals established by the Food and Agriculture Organization of the United Nations (FAO/UN) when it defined the Year 2021 International of Fruits and Vegetables. Producing food for a growing population requires much more than producing with sustainable practices, as distributing, preserving, and developing new products efficiently, ensuring quality, nutrition and safety is our constant concern.

Thus, choosing the strategic food matrix for the development of new products is one of the first objectives when seeking to innovate the market, guaranteeing nutrition. Thus, we emphasize that investing in technologies is essential to guarantee products and improve the entire supply chain. Fruit growing is one of the fundamental sectors, especially in tropical countries like Brazil.

Acerola is defined worldwide as a superfruit for its high concentration of ascorbic acid, which is one of the most important water-soluble vitamins. In addition to provitamin A, vitamins B1 and B2. The fruit has a range of phytonutrients such as phenolics, flavonoids, anthocyanins and carotenoids. Regarding the extract, many studies have shown that the antioxidant activity of acerola extract was much higher compared to extracts rich in polyphenols from other fruits, such as açaí, cherry, grape, mango and strawberry.

The research carried out in each chapter of this work shows the versatility of the fruit and its industrial potential in the development of new products. Thus, in each chapter we seek to define thermophysical properties, efficient thermal processing, mathematical modeling and new product development. We hope that the work will be an instrument of application, contributing more and more to the innovative potential of Brazil worldwide.

The authors

Chapter I

THERMOPHYSICAL PROPERTIES OF ACEROLA PULP (Malpighia emarginata DC)

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Anna Paula Rocha de Queiroga
Ana Carla de Oliveira Brito

Introduction

The high number of fruit species present in Brazil classifies it as a country with great biodiversity. The variety of fruit and exotic species represent a great potential for industries, favoring the development of new products that are pleasing to the taste of consumers (SOUZA et al., 2012; ASSUMPÇÃO et al., 2013).

Acerola (Malpighia emarginata DC.), is a guided fruit in South and Central America and grows in tropical and subtropical climates (LEFFA et al., 2014). With a pleasant flavor and high content of antioxidant compounds, such as ascorbic acid, carotenoids, and phenolic compounds, they led to an increase in consumption in the "in natura" form or in industrialized products, such as pulps, juices, jellies, concentrates and ice cream. These characteristics increase the applicability of the fruit's bioactive compounds, increasing its commercial value (ROCHA, 2019).

Several studies have reported particularly high values of ascorbic acid and appreciable amounts of phenolic compounds in acerola fruits such as anthocyanins and a high antioxidant activity compared to other fruits considered important composite sources such as grapes, açaí, strawberries, cherry, and mango (CHANG, et al., 2019)

The increased demand in the national and international market for acerola pulp is due to its nutritional properties. Acerola stands out for containing several phytochemicals, which are natural substances present in fruits with antioxidant, antimicrobial, anticarcinogenic, anti-inflammatory properties, preventing the oxidation of low-density proteins with a preventive action against neurodegenerative diseases. Regarding the extract, many studies have shown that the antioxidant activity of acerola extract was much higher compared to extracts rich in polyphenols from other fruits, such as açaí, cherry, grape, mango and strawberry (CHANG et al., 2019).

Acerola has high water activity making it highly perishable after harvesting due to increased respiratory rate. Water is the most important component of food products, as it exerts a strong influence on process variables, product characteristics and stability attributes, requiring efficient conservation and storage techniques (LIMA, 2016; OLIVEIRA, 2020).

Therefore, fruit processing becomes essential for the product to be less perishable, in addition to enabling greater value addition to the product. However, it is necessary that these products have adequate nutritional and sensory characteristics, also having an effective quality control and good hygiene conditions (SILVA et al., 2016).

In Brazil, the quality of fruit pulps is regulated by Normative Instruction n.1, of January 7, 2000, which determines the Identity and Quality Standards (PIQ). This resolution defines fruit pulp as the unfermented, non-concentrated and undiluted product, obtained from pulpy fruits through an adequate technological process, with a minimum content of total solids, coming from the edible part of the fruit (BRASIL, 2000).

In Brazil, the quality of fruit pulp is regulated by Normative Instruction No. 1, of January 7, 2000, which determines the Identity and Quality Standards (PIQ). This resolution defines fruit pulp as the unfermented, non-concentrated and undiluted product, obtained from fleshy fruits through an adequate technological process, with a minimum content of total solids, coming from the edible part of the fruit (BRASIL, 2000).

Therefore, determining the thermophysical properties of fruit pulps or juices is essential to define the processing conditions. In the design of equipment for fruit processing, the knowledge of properties linked to their patterns of rheological behavior determines its design and dimensioning of pumps, filters, pipes, among others (PELEGRINE et. al., 2000).

Therefore, the thermal characterization of pulps depends on their chemical composition, as the pulp concentration can expand or contract depending on the processing condition.

In processing, there is the application of thermal processes that involve heat transfer, such as heating, cooling, and freezing. In addition, the physical complexity of food matrices is poorly researched, so predicting the thermal characteristics and thermophysical properties becomes essential (FONTAN et al., 2018)

Determining the thermophysical properties of fruit pulps is very important to design the heat treatment applied to food, as they are essential in modeling, simulation, and optimization studies of industrial processes, especially when operating costs as well as food quality and safety are the main issues elements to be evaluated (COSTA et al., 2018).

In addition, there are few researches related to thermophysical properties, among which we highlight cashew (OLIVEIRA et al., 2020); seriguelas (SILVA et al., 2020); buriti (CAMELO-SILVA et al., 2021); green coconut pulp (SILVA et al., 2020); various fruits (MUKAMA et al., 2020), pineapple and acerola (ALVES et al., 2018), mango (BOM et al., 2010).

Within this context, this work aims to evaluate the thermophysical properties of acerola pulp commercialized in the local market through theoretical correlations.

Methodology

The acerola (*Malpighia emarginata* DC.) pulps of 5 different commercial brands were purchased in supermarkets with greater sales flow located in the city of Campina Grande – PB, then transported in thermoboxes for further analysis. The analyzes were performed at the Food Engineering Laboratory (LEA), located at the Center for Natural Resources and Technology (CTRN) of the Federal University of Campina Grande, Campina Grande – Paraíba.

The fruit is indehiscent, with a diameter of 1 to 3 cm, and weighs from 3 to 16g. Its size can vary according to the genetic potential of the plant, cultural treatments, and the number of fruits per armpit (COSTA, 2013).

Figure 1. Acerola (*Malpighia emarginata* DC) used in the samples.

In the samples, the following properties were determined:

Water content and total solids contente

To determine the water content, this experiment was carried out in a vacuum oven at 70°C, with 5g DE samples in capsules, previously tared, and heated for 6 hours, under reduced pressure ≤ 100mm of mercury (13.3 kPa), cooled in a desiccator to room temperature, weighed and repeated this operation until constant weight (BRASIL, 2008). The total solids content was determined by difference according to Equation 1.

$$ST = (100 - TA) \qquad \text{(Eq.1)}$$

Where: ST is the total solids content (g/100g); TA is the water content (g/100g).

Total soluble solids content

The total soluble solids content was determined by refractometry, using a benchtop digital refractometer and the results were expressed in °Brix (BRASIL, 2008).

Theoretical specific mass

The theoretical specific mass was calculated using Equation 2, proposed by Alvarado and Romero (1989) as a function of temperature and total soluble solids concentration.

$$\rho = 1002 + 4{,}16A - 0{,}460T + 7{,}001x10^{-3}T^{2} - 9{,}175x10^{-5}T^{3} \qquad \text{(Eq.2)}$$

Where: is the specific mass (kg/m³); A is the total soluble solids content (°Brix); T is the temperature (°C).

Theoretical thermal conductivity

The theoretical thermal conductivity (k) was determined using Equation 3 proposed by Pereira et al. (2003) as a function of total solids content.

$$k = 0{,}53978 + 0{,}00418xB \qquad \text{(Eq.3)}$$

Where: k is the thermal conductivity (W/m °C); B is the total solids content (g/100g).

Theoretical specific heat

The theoretical specific heat was calculated using the empirical equation (Equation 4) proposed by Vieira (1996) as a function of the concentration of total soluble solids.

$$C_p = 4{,}1713 - 0{,}0279xA \qquad \text{(Eq.4)}$$

Where: Cp is at specific heat (kJ/kg °C); A is the total soluble solids content (°Brix).

Statistical analysis

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 5% significance level. For the development of statistical analyzes the ASSISTAT software version 7.0 was used.

Results

Table 1 shows the values obtained for the water content, total solids and total soluble solids of the acerola pulp.

Table 1. Water content, total solids and total soluble solids of acerola Pulp

Samples	Water content (g/100g)	Total solids content (g/100g)	Total soluble solids content (°Brix)
A1	70,74^{e}	29,26^{a}	5,66^{e}
A2	72,75^{d}	27,25^{b}	6,00^{d}
A3	78,78^{a}	21,22^{e}	6,50^{c}
A4	76,59^{b}	23,41^{d}	7,00^{b}
A5	74,52^{c}	25,48^{c}	8,20^{a}

Note: Equal superscript lowercase letters in the same column do not differ significantly between the analyzed tags.

The water content of a food is related to its stability, quality and composition (CECCHI, 2003). In the case of fruit pulps, this parameter is not directly treated as a quality identifier, as it is a product that has a high water content. Of the samples analyzed, the one with the highest water content was the A3 pulp (78.78g/100g) as shown in Table 1. When the analyzed brands were statistically compared with each other, the values showed a significant difference at a level of 5% of probability.

This variation in water content is a consequence of the cultivar, harvest maturation stage and water availability in the fruit, as well as the relative humidity of the ambient air, in which if the air humidity is lower, the fruit tends to lose water to the environment, but is also related to an increase in the respiratory rate and ethylene production, followed by a sharp decline in the onset of senescence (NERIS et al., 2018).

Observe high solids contents, between 21.22g/100g and 29.26g/100g, these values being higher than the PIQ, which is a positive point and guarantees the quality and acceptability of the product. When the brands analyzed were statistically compared with each other, the values showed a significant difference at a 5% probability level. Machado (2017) found an average value of 7.28 for artisanal acerola pulp.

The soluble solids content obtained for the five different acerola pulps differed significantly from each other, varying between (5.45 – 8.20 °Brix) these values are allowed and fall within the minimum acceptable by law. Brazil (2016), when determining the soluble solids content in different pulps commercialized in Cuiába -MT, they obtained values that varied between (6.50 -7.50 ºBrix) for acerola pulps.

The content of total soluble solids 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 genetic characteristics of the material. In addition, this parameter represents one of the best ways to assess the degree of sweetness of the product, which is greater with the evolution of maturation, due to the biosynthesis processes or even the degradation of polysaccharides (CHITARRA & CHITARRA, 2005; RAMOS et al., 2013; BOTELHO et al., 2019).

Table 2 shows the theoretical values obtained for specific mass of acerola pulp at temperatures of 25 and 45°C.

Table 2. Theoretical specific mass of acerola pulp at temperatures of 25 and 45°C

Samples	**Theoretical specific mass (kg/m³)**	
	25°C	**45°C**
A1	$1044{,}29^{Ae}$	$1037{,}96^{Be}$
A2	$1055{,}50^{Ad}$	$1049{,}07^{Bd}$
A3	$1080{,}71^{Aa}$	$1074{,}38^{Ba}$
A4	$1071{,}35^{Ab}$	$1065{,}03^{Bb}$
A5	$1062{,}36^{Ac}$	$1056{,}04^{Bc}$

Note: Equal superscript lowercase letters in the same column do not differ significantly between the analyzed tags; Equal superscript capital letters on the same line do not differ significantly between the temperatures studied.

The theoretical specific mass of acerola pulp showed a statistically significant difference between the analyzed brands evaluated and between the predicted temperatures. A reduction is observed when the temperature is increased from 25 to 45°C.

According to Oliveira et al. (2020), the behavior of the specific mass in relation to temperature is related to the phenomenon of expansion of the pulp volume, because with the increase in temperature, the fluid molecules vibrate at high speeds, thus increasing the distance between them (CHIN et al., 2008; MERCALI et al., 2011).

Table 3 shows the theoretical values of thermal conductivity and specific heat of the acerola pulp.

Table 3. Theoretical thermal conductivity and specific heat of acerola Pulp

Samples	**Theoretical thermal conductivity (W/m °C)**	**Theoretical specific heat (kJ/kg °C)**
A1	0,662^{a}	4,01^{a}
A2	0,654^{ab}	4,00^{a}
A3	0,628^{c}	3,98^{a}
A4	0,638^{b}	3,97^{a}
A5	0,646^{b}	3,94^{a}

Note: Equal superscript lowercase letters in the same column do not differ significantly between analyzed tags.

The theoretical thermal conductivity of acerola pulp presented values below 0.7 W/m °C. Statistically, sample A5 showed a significant difference when compared to the others, at a 5% probability level. Regarding the theoretical specific heat, there was a reduction in its values from 4.01 to 3.94 kJ/kg °C between the brands analyzed, statistically these reductions were not significant at the 5% probability level.

Muniz et al. (2006) obtained thermal conductivity values of bacuri pulp ranging from 0.64 to 0.50 W/m °C when the total soluble solids content increased from 5 to 20 °Brix. Moura et al. (2016) when determining thermophysical properties of fruit-based products obtained through theoretical correlations the following values for a red fruit smoothie 0.54 W/m °C for thermal conductivity and 4.18 kJ/kg °C for heat specific.

The sizing of equipment used in food processing, especially those that work with pumping and heat transfer, requires precise data on the thermal properties of fluid and semi-solid foods (density, thermal conductivity, thermal diffusivity and specific heat) and how these properties match. Behave during the process, depending on the temperature (ROUSTAPOUR & GAZOR, 2013; MOURA et al., 2016).

Conclusion

The water content, total solids and total soluble solids of acerola pulp had significant differences for the five different brands analyzed.

Thermophysical properties such as theoretical specific masses suffered from the predicted temperature.

The specific heat showed a reduction in its values among the brands analyzed due to the increase in soluble solids in the pulp.

As suggestions for future work, it is possible to determine the thermophysical properties of acerola pulp experimentally and carry out a comparative study with the values obtained through empirical correlations that are obtained as a function of the composition of the product.

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Chapter II

DRYING OF ACEROLA (Malpighia emarginata DC) PULP IN FOAM-MAT

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Introduction

Acerola (*Malpighia punicifolia* L.) is a fruit of great nutritional value for presenting high concentrations of ascorbic acid, which can reach values of 5%, adding a high nutritional potential for the consumption of fresh or industrialized fruit (REIS et al., 2017).

According to Malegori et al. (2017), the acerola is characterized by a succulent pulp and protective skin that, when ripening, changes its color from green to reddish-yellow and finally to red or purple, when fully ripened, depending on the variety. The pigment shift is linked to complex biochemical changes involving all its major compounds, such as carotenes, thiamine, riboflavin, niacin, calcium, phosphorus and vitamin C.

It is a climacteric fruit with a very high respiratory rate (900 ml CO_2 kg $^{-1}$ h $^{-1}$) and a low peak ethylene production rate (3 µl C_2H_4 kg $^{-1}$ h $^{-1}$) (PRAKASH et al., 2018).

Like other fruits, acerola is also perishable, fragile, with a short shelf life, representing an obstacle to its fresh commercialization, it is recommended that it undergo processing so that it can reach more distant consumer markets and supply its products all year round whole. Processing, in addition to adding value, increases its useful life, can facilitate transport and the development of new products. It is in this scenario that drying in a foam layer appears as an alternative to be used in the conservation of this fruit (OLIVEIRA et al., 2015).

Drying in a foam layer is a process often used in the dehydration of heat-sensitive foods, such as fruit pulp, providing retention of the nutritional and sensory properties of the fresh fruit. It is a simple process with appreciable advantages, which requires little equipment and involves shorter processing times compared to lyophilization, for example (ALEXANDRE et al., 2014).

It consists of transforming a liquid or pasty food into a stable foam by incorporating air and subsequently forming bubbles in the food. This procedure increases the contact area between the drying air and the food, improving mass transfer, as well as heat transfer due to the increase in the surface heat exchange area (ARAÚJO et al., 2020).

Capillarity through the foam pores facilitates the loss of moisture, so the speed of drying over a layer of foam is much more efficient than drying a layer of liquid. Thus, at the end of the process, the foam is fragmented and a powder product similar to that obtained by spraying and lyophilization is published. Drying results in a porous and brittle product, easy to grind and transform into powder with good rehydration properties (FELLOWS, 2000).

The stability of the foams is fundamental for the quality of the product, increasing the interaction area during the entire drying process. The raw materials contain compounds that help in the production of foams but are insufficient to form a stable foam. Thus, using agents that contribute to form and stabilize the foam is important and necessary (BAG et al., 2011).

Stabilizers provide changes in the characteristics of their constituents to obtain a porous product that can be easily dehydrated. Some of the widely used stabilizers are albumin, egg white, emustab®, maltodextrin and gums (GUAZI, 2016).

Furthermore, the properties of the powder, such as fluidity, cohesiveness, rehydration and hygroscopicity, are improved by the foam mat drying method (NG & SULAIMAN, 2018). Some researches have already used foam bed drying for food products such as: raspberry (OZCELIK et al., 2019); strawberry (VIMERCANTI et al., 2019); mango (CHAUX-GUTIÉRREZ et al., 2017; WILSON et al., 2012), Indian gooseberry (METHAKHUP et al., 2005); melon pulp (SALAHI et al., 2017), tomatoes (AZEEZ et al., 40 2017); banana (NAKNAEN et al., 2016), shrimp (AZIZPOUR et al., 2013).

Drying methods allow the processing of powdered fruit, increasing the product's shelf life and added value, allowing its use in a wide range of food formulations on an industrial scale. The storage conditions of the dehydrated product must be known to maintain the quality of the product, such as better environmental and packaging conditions to protect against external influences (MACIEL et al., 2020).

Through the drying kinetics it is possible to determine the behavior of the dry material, representing it by curves and drying rates. Several mathematical models have been used to describe the drying process of agricultural products and to determine the process information, which can be used in future equipment designs (SANTOS et al., 2020).

In this context, the present work aims to elaborate the acerola pulp foam and determine its physical properties (specific mass and expandability), perform the drying kinetics at temperatures of 50, 60 and 70°C and adjust empirical and diffusive mathematical models, thus contributing to the development of future projects for drying equipment and for agribusiness.

Methodology

They were used with raw materials such as acerola (*Malpighia punicifolia* L.), skimmed bed powder and the additives: emustab and neutral alloy, all of which were purchased from the local commerce. Initially, acerola went through the steps of cleaning, sanitizing, sanitizing in a sodium hypochlorite solution (200 mg L^{-1} of free chlorine) for 15 min and washing in running water. Then, with the aid of a domestic blender, without adding water, the fruits were processed, and their pulp was obtained.

Figure 1. Acerola (*Malpighia emarginata* DC) used in the samples.

Foaming

The acerola pulp foam was prepared according to the ingredients and conditions shown in Table 1.

All ingredients were weighed separately and mixed using a domestic mixer during (20 min) of agitation, using its maximum speed, after which time the foam was obtained and its physical properties were evaluated.

Table 1. Ingredients and conditions used to prepare the acerola pulp foam

Ingredients and conditions	Quantities
Acerola pulp (%)	85.5
Skimmed milk powder (%)	10
Neutral Alloy (%)	0.5
Emustab (%)	4
Beating time (min)	20

Physical properties of foam

A specific mass (g cm^{-3}) (Equation 1) and expandability (%) (Equation 2) of acerola pulp foam calculated according to the equations described by Oguntunde and Adeojo (1993) and Dehghannya et al. (2019).

$$\rho_f = \frac{m}{V} \qquad \text{(Eq.1)}$$

$$Exp(\%) = \frac{\frac{1}{\rho_f} - \frac{1}{\rho_p}}{\frac{1}{\rho_p}} x100 \qquad \text{(Eq.2)}$$

Where: ρ_f is the specific mass of the foam (g cm^{-3}); ρ_p is the specific mass of the avocado pulp (g cm^{-3}); *m* is the mass (g); *V* is the volume (cm^{-3}); *Exp* is the expandability (%).

Drying kinetics

The drying kinetics was carried out at temperatures of 50, 70 and 90°C, being carried out in a fixed air circulation oven with a speed of 1.0 m s^{-1}. The foams were evenly placed on aluminum trays forming a 5 mm thin layer. 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 registered.

Calculation of moisture ratio

The moisture ratio of the drying process was calculated according to Equation 3.

$$X^*(t) = \frac{X(t) - X_{eq}}{X_i - X_{eq}} \qquad \text{(Eq.3)}$$

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 t moment (dry basis) and X_i is the initial moisture content (dry basis).

Empirical model

The empirical mathematical model of Page (Equation 4) was fitted to experimental data of the drying kinetics of acerola pulp foam using the computer program LAB Fit® (SILVA & SILVA, 2008) through non-linear regression, by the Quasi-Newton method.

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

Where, X^* is the moisture ratio (dimensionless); “a” e “b” constant on the model.

The model fitting was evaluated by the determination coefficient (R^2) (Equation 5), the chi-squared (χ^2) (Equation 6) and mean square deviation (MSD) (Equation 7).

$$R^2 = \frac{\sum_{i=1}^{N}\left[(X^*_{\exp,i} - \overline{X^*_{\exp,i}}).(X^*_{pre,i} - \overline{X^*_{pre,i}})\right]^2}{\sum_{i=1}^{N}(X^*_{\exp,i} - \overline{X^*_{\exp,i}})^2.\sum_{i=1}^{N}(X^*_{pre,i} - \overline{X^*_{pre,i}})^2.} \qquad \text{(Eq.5)}$$

Where: $X^*_{\exp,i}, \overline{X^*_{\exp,i}}, X^*_{pre,i}, \overline{X^*_{pre,i}}$, N and n are the experimental dimensionless moisture content, mean of the experimental dimensionless moisture content, dimensionless moisture content predicted by the model, mean of the dimensionless moisture content predicted by the model, number of observations and number of coefficients (constants) of the model, respectively.

$$\chi^2 = \frac{1}{N-n}\sum_{i=1}^{N}\left(X^*_{\exp,i} - X^*_{pre,i}\right)^2 \qquad \text{(Eq.6)}$$

Where, χ^2 is the chi-squared function, $X^*_{\exp,i}$ is the experimental moisture ratio, $X^*_{pre,i}$ is the simulated moisture ratio, N is the number of experimental points, and n is the number of coefficients and constants on the model.

$$MSD = \left[\frac{1}{N}\sum_{i=1}^{N}\left(X^*_{\exp,i} - X^*_{pre,i}\right)^2\right]^{\frac{1}{2}} \qquad \text{(Eq.7)}$$

Where, MSD is mean square deviation, $X^*_{\exp,i}$ is the experimental moisture ratio, $X^*_{pre,i}$ is the simulated moisture ratio, and N is the number of experimental points.

Diffusivity calculation

The effective diffusivities (Def) of the sample at different drying temperatures (50, 60 and 70°C) were determined using the diffusion equation (Equation 8) for rectangular coordinate systems (CRANK, 1975). In calculating Def, the analytical solution for Fick's second law of diffusion was applied in the form of an infinite series (Equation 9).

$$\frac{\partial X}{\partial t}=\frac{\partial}{\partial x}\left(Def\frac{\partial X}{\partial x}\right)+\frac{\partial}{\partial y}\left(Def\frac{\partial Y}{\partial y}\right)+\frac{\partial}{\partial z}\left(Def\frac{\partial Z}{\partial z}\right) \quad \text{(Eq.8)}$$

$$X^{*}=\frac{8}{\pi^{2}}\sum_{n=0}^{\infty}\frac{1}{(2n+1)}\exp\left[-(2n+1)^{2}\pi^{2}\frac{Def}{L^{2}}t\right] \quad \text{(Eq.9)}$$

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).

Results

Table 2 shows the values of the physical properties of the acerola pulp foam produced under the conditions shown in Table1.

Table 2. Physical properties obtained for acerola foam

Physical properties	Acerola foam
Specific mass (g cm $^{-3}$)	0.500 ± 0.34
Expandability (%)	107.017 ± 0.49

It is observed that the acerola pulp foam had a specific mass of 0.500 g cm^{-3} and 107.017% expansion. This high expansion value and low specific mass value are related to the concentration of the foaming agent. Dantas (2010), in his studies with different fruit pulp foams, obtained the following specific mass values for foams: umbu (0.55 g cm^{-3}), mango (0.51 g cm^{-3}), seriguela (0.41 g cm^{-3}) and pineapple (0.24 g cm^{-3}), even in the same study, it was possible to observe that the same foams evaluated presented expansion values above 100%.

Table 3 shows the parameter values of the mathematical model of Page adjusted to the experimental data of the acerola pulp foam drying kinetics at temperatures of 50, 60 and 70ºC. The values of parameter “a” did not show a defined behavior with an increase in temperature.

Table 3. Page mathematical model parameters

Temperature (°C)	Model parameters	
	a	**b**
50	0.2325×10^{-2}	1.0821
60	0.1466×10^{-3}	1.7089
70	0.2810×10^{-2}	1.3417

An increase in the values of parameter "b" from 1.0821 to 1.3417 can be observed, according to Nascimento et al. (2018) parameter "b" tends to increase since higher temperatures lead to higher drying rates, reaching equilibrium water content in less time for product submission to drying air. Table 4 shows the values of the statistical parameters: coefficient of determination (R^2), chi-square function (χ^2) and mean square deviation (MSD).

Table 4. Statistical parameters obtained by adjusting Page's mathematical model

Temperature (°C)	Statistical parameters		
	R^2	χ^2	**MSD**
50	0.9975	0.7762×10^{-2}	0.0125
60	0.9997	0.6945×10^{-3}	0.0206
70	0.9929	0.1252×10^{-1}	0.0153

For the temperatures at which the acerola pulp foams were submitted (50, 50 and 70°C), the coefficient of determination (R^2) values were higher than 0.99. The chi-square function presented low values (0.7762×10^{-2}; 0.6945×10^{-3}; 0.1252×10^{-1}) and the mean square deviation also presented values less than 0.1. Even when the statistical parameters present good results, the model can be ineffective if it presents a biased residual distribution (SANTOS et al., 2019).

Therefore, in Table 5, it is possible to observe that the mathematical model of Page presented a random distribution of residues for all applied temperatures, showing that the model presented a good fit to the data.

Table 5. Waste distribution

Temperature (°C)	Waste distribution
50	Random
60	Random
70	Random

The values obtained in the calculation of the effective diffusivity, using the analytical solution for Fick's second law of diffusion, are shown in Table 6.

Table 6. Effective diffusivity of the acerola pulp foam drying process at temperatures of 50, 60 and 70ºC

Temperature (°C)	Diffusivity (m^2 min^{-1})	R^2
50	1.3967×10^{-5}	0.9949
60	2.3917×10^{-5}	0.9954
70	5.4528×10^{-5}	0.9915

It is observed that the diffusivity values increased with when there were higher temperature gradients, ranging from 1.3967 to 5.4528 x 10^{-5} m^2 min^{-1}, in addition, it presented a satisfactory adjustment with R^2 values greater than 0.99.

This increase in effective diffusivity with increasing temperature can be associated with increased vapor pressure inside the foam (ASOKAPANDIAN et al., 2016). Silva et al. (2021) in their studies of drying with persimmon pulp foam, obtained effective diffusivity values ranging from 9.43 to 33.50 x 10^{-8} m^2 s^{-1}, presenting an adjustment with coefficient of determination above 0.9667.

Baptestini et al. (2015) obtained diffusivity values ranging from 4.12 to 17.66 x 10-10 m^2 s^{-1} when performing the soursop foam drying process at temperatures ranging from 40 to 80°C.

Freitas et al. (2018) obtained values ranging from 5.18 to 26.80 x 10^{-9} m^2 s^{-1} in their studies of foam drying of cajá pulp at temperatures ranging from 50 to 80°C.

Conclusion

The foam made with acerola pulp, skimmed milk powder and emulsifiers, presented satisfactory physical properties with a low specific mass value and a high percentage of expansion.

Page's mathematical model fitted well with the experimental data of foam drying of acerola pulp, showing good statistical parameters and random waste distribution.

Effective diffusivity increased with increasing drying temperature, with the highest value (5.4528 x 10-5 m^2 min^{-1}) being obtained for a temperature of 70°C.

Thus, the results presented in this study are of great relevance for the agribusiness and for the development of new drying equipment.

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Chapter III

PREPARATION, PHYSICOCHEMICAL, BIOACTIVE AND MICROBIOLOGICAL CHARACTERIZATION OF ACEROLA (*Malpighia emarginata* DC) ICE CREAM WITH GOAT'S MILK

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Introduction

Ice cream is a valuable addition to the normal diet for all age groups, especially for children. It is one of the most consumed dairy products. Brazil is the sixth largest producer of ice cream in the world, behind the United States, China, Russia, Japan, and Germany (FISPAL, 2019).

The quality and variety in ice cream manufacturing has gained importance in the dairy industry. Ice cream contains micronutrients, that is, calcium and vitamins (E, D, A), as well as rich in macronutrients, that is, fats, carbohydrates, and proteins (ISMAIL et al., 2020).

Currently, ANVISA (National Health Surveillance Agency), through resolution RDC No. 266 of September 22, 2005, establishes edible ice creams as food products obtained from an emulsion of fats and proteins, with or without the addition of other ingredients and substances, or a mixture of water, sugars and other ingredients and substances that have been subjected to freezing, under conditions such as to ensure the conservation of the product in the frozen or partially frozen state, during storage, transport and delivery for consumption they can be added with other ingredient(s) as long as they do not mischaracterize the product (BRASIL, 2005).

Acerola (*Malpighia emarginata* DC) is a fruit rich in antioxidant compounds, such as vitamins, carotenoids, and polyphenols. Acerola is known to be one of the richest fruits in vitamin C content, but much attention has been paid to the carotenoid content due to its antioxidant properties. In Brazil, this fruit has great economic importance, as it is consumed fresh and industrialized (MONTEIRO et al., 2020).

Goat milk is the product of complete, uninterrupted milking, under hygienic conditions, of healthy, well-fed, and rested goat animals, becoming a nutritionally rich food by providing nutrients such as minerals, vitamins, easily digestible proteins, amino acids with an adequate nutritional profile and essential fatty acid, important in most body functions (COELHO et al., 2018).

Goat milk-derived products have a high added value due to their sensory characteristics and their appeal to consumers, in addition to being considered "healthy food" (PÁDUA et al., 2019).

Goat milk has an average of 4.25% fat: 3.52% protein, 4.27% lactose, 0.86% ash, 8.75% non-fat solids and 13% total solids. However, protein and fat are of fundamental importance, due to their contribution to the yield, sensory characteristics, and flavor of dairy products (COELHO et al., 2018). Goat milk is one of the most complete foods, under the point of nutritional view, providing numerous alternatives for industrialization and transformation into derived products (SILVA & FAVARINS, 2020).

In addition, it should be noted that it has several immunogenic proteins and bioactive peptides, in addition to having low allergenicity and easy digestibility. Compared to cow's milk, goat's milk contains more minerals and vitamins A, B and C milk, less high, low and medium chain cholesterol and fatty acids (PARK, 2017).

Ice cream is a dessert widely consumed in Brazil and, for this reason, it is a great vehicle for incorporating functional and regional ingredients, such as acerola and goat's milk. The purpose of incorporation is to make this frozen dessert a nutritionally enriched product, as the modern consumer wants foods that meet their requirements in a healthy way (LAMOUNIER et al., 2015).

Acu et al. (2021) state that ice cream made with goat's milk, which, in addition to nutritional characteristics, has sensory characteristics such as flavor, color, melting and texture, in addition they highlight that when goat milk is used in the production of ice cream, the ice cream color becomes whiter.

In this context, the present study aims to prepare an ice cream with different concentrations of acerola pulp and goat milk and characterize the formulations regarding physicochemical, bioactive, and microbiological parameters.

Methodology

The acerola (*Malpighia emarginata* DC) used in this study were purchased from local stores. The fruits were selected, washed, and sanitized with sodium hypochlorite in solution (200 mg. L^{-1} of free chlorine), after complete sanitization, the fruits were processed in a domestic blender, thus obtaining the acerola pulp.

Figure 1. Acerola (*Malpighia emarginata* DC) used in the samples.

Ice cream making

Ice cream production was carried out using the following unit operations:

(1) Weighing the ingredients according to the amounts described in Table 1;

(2) Initial mix of goat's milk, neutral alloy and sugar in a blender for 3 min;

(3) Freezing the initial mix;

(4) Cutting the initial frozen mix;

(5) Addition of other ingredients;

(6) Mixing ingredients in an electric mixer for 12 min;

(7) Filling the ice cream in polypropylene pots with lids;

(8) Freezer storage at –18°C.

Table 1. Ice cream formulations with different concentrations of acerola pulp

Ingredients	F1 (%)	F2 (%)	F3 (%)
acerola pulp	20	40	80
Goat milk	47.90	40.90	13.58
Sugar	10.5	6.3	2.1
Neutral Alloy	0.3	0.018	0.06
Milk cream	20.8	12.48	4.16
Emulsifier	0.5	0.3	0.1
Total (%)	100%	100%	100%

Source: adapted from Czaikoski et al. (2016).

Physicochemical characterization of formulations

The elaborated formulations were characterized in triplicate according to the following parameters: moisture content, ash, proteins, lipids according to the methodology of Instituto Adolfo Lutz (BRASIL, 2008). The total carbohydrate content was calculated by difference to obtain 100% of the total composition (FAO, 2003). The water activity of the samples was determined in Aqualab 3TE (DECAGON, DEVICES USA).

Determination of vitamin C and total anthocyanins

Vitamin C content was determined through the reaction of ascorbic acid with 2,6-dichlorophenol indophenol (DCFI), as described by Brasil (2008), and the results were expressed in mg ascorbic acid/100g sample. The total anthocyanin content was determined following the unique pH method described by Francis (1982).

Microbiological analysis

For microbiological evaluation, a 25 g portion of the product was homogenized in 225 g of saline solution. For confirmation of *E. coli*, EMB Agar culture medium was used, the plates were inoculated from positive tubes of EC broth in an oven at 3ºC for 24 hours. In checking for Salmonella spp, a 25g portion of the sample was contained in peptone saline water and incubated at 35°C for 24 hours. The incubated sample was transferred to a Petri dish and incubated at 35°C for a period of 24 hours.

Statistical analysis

The experimental data were analyzed in triplicate and the results were submitted to the analysis of variance of a single factor (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 analysis, the software Assistat 7.7, Silva e Azevedo (2016) was used.

Results

Table 2 shows the mean values of water activity obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk.

Table 2. Mean values ± standard deviation of water activity of the different formulations of acerola ice cream with goat's milk

Formulations	Water activity (aw)
F1	0.901 ± 0.01 [to]
F2	0.915 ± 0.00 [to]
F3	0.9 23 ± 0.02 [a]

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The water activity values obtained were greater than 0.9 (aw > 0.90), not significantly different from each other in the Tukey test with a level of 5%. Values close to those of the present study were reported by Correia et al. (2008) when making ice creams with cow's milk (0.982) and goat's milk (0.979). According to Ramos et al. (2021) carbohydrates have a high power of association with water, influencing water activity, as many are used as sweeteners, contributing to texture and taste.

In Figure 1, the average values of the moisture content obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk are presented.

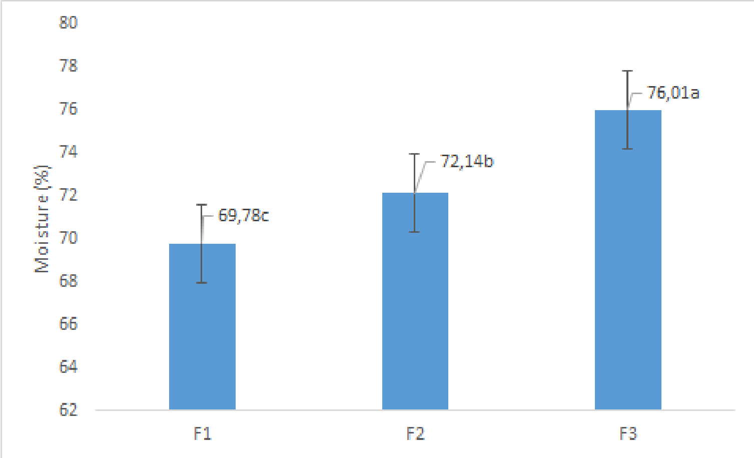

Figure 1. Moisture content of different formulations of acerola ice cream with goat's milk. Note: Means with equal letters do not differ significantly from each other to the Tukey test at the 5% level.

In determining the moisture content of different formulations of acerola ice cream with goat's milk, it was obtained levels ranging from 69.78 to 76.01%, statistically the values obtained showed significant differences at the level of 5% probability. Formulation F3 had the highest moisture content (76.01%) which may be related to the highest amount of acerola pulp in its composition (80%).

Ismail et al. (2020) when preparing different formulations of ice cream enriched with pomegranate peel, they obtained lower moisture contents than in the present study, ranging from 64.82 to 68.7%. Morzelle et al. (2012), when analyzing ice cream based on fruits from the cerrado, they found values between 65.23 and 67.52% for pequi and araticum, respectively.

In Figure 2, the average values of the ash content obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk are presented.

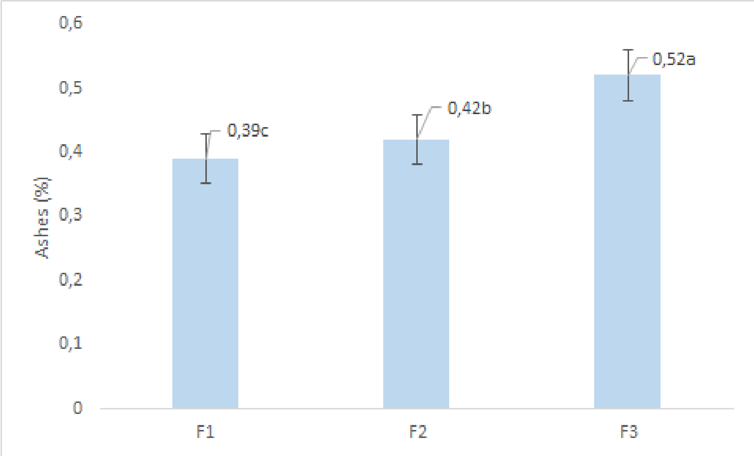

Figure 2. Ash content of different formulations of acerola ice cream with goat's milk. Note: Means with equal letters do not differ significantly from each other to the Tukey test at the 5% level.

All formulations differed statistically ($p < 0.05$) for ash content. There was a variation from 0.39 to 0.52% of ash, with the highest content being obtained for the formulation (F3). A value close to that of the present study was obtained by Oliveira et al. (2019), 0.40% in their studies with açaí ice cream. Lamounier et al. (2015), by characterizing different formulations of ice creams enriched with jabuticaba husk flour, they obtained ash contents from 0.90 to 1.07%, results superior to those found in this study.

In Figure 3, the average values of the lipid content obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk are presented.

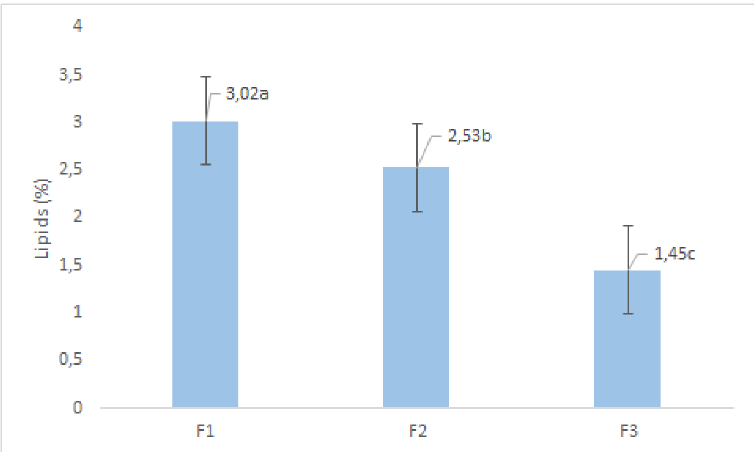

Figure 3. Lipid content of different formulations of acerola ice cream with goat milk. Note: Means with equal letters do not differ significantly from each other to the Tukey test at the 5% level.

A significant variation ($p<0.05$) can be observed in the lipid values in the different formulations, which presented values ranging from 1.45 to 3.02%. Formulation F1 had the highest lipid content (3.02%) which can be explained by the concentrations of cream (20.8%) in its composition. Values higher than those in the present study were observed by Vacandio et al. (2013), who, when preparing ice cream with yacon aqueous extract, obtained 5.20 and 5.45% of lipids.

In Figure 4, the mean values of the protein content obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk are presented.

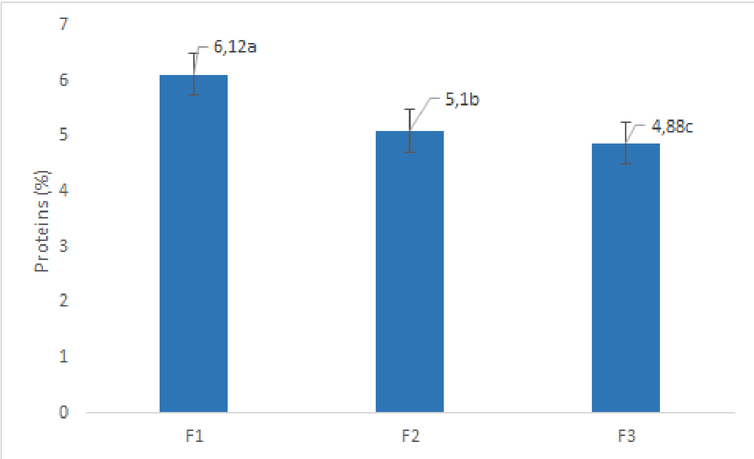

Figure 4. Protein content of different formulations of acerola ice cream with goat's milk. Note: Means with equal letters do not differ significantly from each other to the Tukey test at the 5% level.

For protein content, values greater than 4% were observed for the three formulations developed. The highest content was 6.12% obtained for the F1 formulation, which contains 47.90% of goat's milk in its composition. Statistically, the mean values obtained showed significant differences from each other to the Tukey test at the 5% level.

Martins (2017), when elaborating and characterizing different formulations of a mixed ice cream, obtained protein contents ranging from 0.95 to 1.85%. Vacandio et al. (2013), when preparing ice cream with yacon aqueous extract, they obtained protein contents of 1.66 and 2.46%. According to Martins (2017), proteins are of great importance for the quality of ice cream, as they influence the beating, emulsification and improve the structure, resulting in a fluffy and voluminous foam.

In Figure 5, the mean values of carbohydrate content obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk are presented.

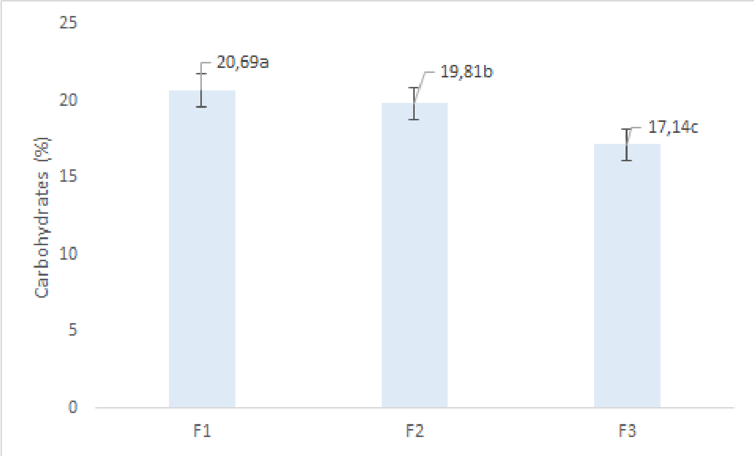

Figure 5. Carbohydrate content of different formulations of acerola ice cream with goat's milk. Note: Means with equal letters do not differ significantly from each other to the Tukey test at the 5% level.

There was a variation from 17.14 to 20.69% of carbohydrates in the elaborated ice cream formulations, with the highest percentage obtained for the formulation (F1), which differs statistically from F2 and F3 at the 5% probability level. Fernandino et al. (2021) when preparing 4 ice cream formulations with 20% and 30% of yellow tamarillo pulp and 20 and 30% with purple tamarillo pulp, they obtained carbohydrate contents of 24.75 and 26.33% for ice cream with pulp of yellow tamarillo and 27.44 and 23.55% for ice cream with purple tamarillo pulp, results superior to those found in the present study.

In Table 3, the mean values of vitamin C and total anthocyanins obtained for the formulations (F1, F2 and F3) of acerola ice cream with goat milk are expressed. For the three formulations, a high level of vitamin C was obtained, which ranged from 192.63 to 426.98 mg/100 g, with a statistically significant difference ($p<0.05$). Braga and Sá (2021) when evaluating the stability of vitamin C in acerola ice cream for 150 days, obtained values ranging from 604.06 to 635.20 mg/100g.

Vitamin C participates in several biological functions, such as increased collagen formation, and is considered one of the main vitamins required by the human body due to its antioxidant properties. In fact, increased intake of antioxidants has been associated with a lower risk of cardiovascular disease (GARCIA et al., 2020).

Table 3. Mean values ± standard deviation of vitamin C and anthocyanin contents of different formulations of acerola ice cream with goat milk

Parameters	**F1**	**F2**	**F3**
Vitamin C (mg/100g)	192.63 ± 1.41^{c}	298.14 ± 2.57 ^{b}	426.98 ± 1.99 ^{a}
Total anthocyanins (mg/100g)	0.96 ± 0.05 ^{c}	1.54 ± 0.11 ^{b}	2.01±0.19 ^{a}

Note: Equal superscripted letters on the same line do not differ significantly from each other by Tukey's test at the 5% level.

It is also possible to observe in Table 3, that the developed formulations presented low concentrations of total anthocyanins. Formulation F1 had the lowest value (0.96 mg/100g) and formulation F3 the highest value (2.01 mg/100g), statistically when comparing the values of anthocyanins obtained between the formulations, these present significant differences between them. Table 4 shows the results obtained for the microbiological parameters analyzed in the formulations (F1, F2 and F3) of acerola ice cream with goat milk.

Table 4. Results obtained in the microbiological analysis of the different formulations of acerola ice cream with goat's milk

Parameters	**F1**	**F2**	**F3**
E. coli	Absent	Absent	Absent
Salmonella sp	Absent	Absent	Absent

The presence of *E. coli* was not detected in the elaborated formulations. According to Lembi et al. (2020), the *E. coli* research is applied as an indicator of hygiene, showing that the fecal material came into contact with food directly or indirectly, so its existence indicates contamination after the procedure, unsatisfactory conditions in heat treatment, cleaning and insufficient sanitation or multiplication during processing and storage.

For *Salmonella sp*., it was observed that all formulations were absent in 25g, meeting the requirements of the current legislation of the Health Surveillance Agency. According to RDC No. 12 of 2001 from ANVISA, ice cream samples must present absence of Salmonella sp. According to Dantas et al. (2012) its presence indicates that the samples were processed under unsatisfactory hygienic-sanitary conditions, presenting risks to the consumer's health.

Due to the fact that ice cream is preserved at low temperatures, the population. He believes that this prevents the growth of microorganisms, but freezing the product does not inhibit the presence of psychrotrophic microorganisms, which are bacteria that grow at temperatures around 7ºC and that may be present in the milk used in the ice cream production process.

Conclusion

The concentration of acerola pulp and goat milk used influenced the physicochemical characteristics of the ice creams.

The F3 formulation with the highest percentage of acerola pulp had the highest levels of moisture, ash, vitamin C and total anthocyanins, however, the F1 formulation with the highest percentage of goat's milk had the highest levels of lipids, proteins and carbohydrates.

From a microbiological point of view, the elaborated ice creams are safe for consumption, not presenting microorganisms harmful to human health.

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Chapter IV

DEVELOPMENT OF COOKIES WITH ACEROLA (*Malpighia emarginata* DC) WASTE FLOUR: CENTRAL COMPOSITION, TEXTURE AND WATER ACTIVITY

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Introduction

The high rates of losses and waste generated by the food industries lead to the search for alternatives for the use and development of new products, which can be added to nutrients and functional appeals. Within the development of new products, by-product flour has been widely used to fortify bakery products and contribute to the reduction and use of agro-industrial residues (LARROSA & OTERO, 2021).

The use of these by-products, in addition to sustainable, environmental and economic factors, is associated with the high fiber content found in its composition. Studies relate dietary fiber intake with health maintenance and disease prevention (BORGES et al., 2021).

The replacement of wheat flour occurs partially or totally in bakery products, depending on the final objective. Some types of flour commonly used are rice, barley, chia, coconut flour, peas, bananas, eggplant, among others. The choice of the type of flour will depend on the desired characteristics of the food (OLIVEIRA et al., 2020).

The use of alternative flours raises an expectation of differentiated bakery products in terms of their sensory, nutritional and physicochemical qualities. However, despite all the socioeconomic and nutritional benefits, the use of these flours is still modest, little known and little known. Most of the product is destined for small craft industries (KHOOZANI et al., 2019).

The biscuit is the product acquired by kneading and baking dough prepared with flour, starches, fermented or not, and other food substances. Its quality is related to flavor, texture, appearance, among other factors, and in recent years it has stood out as a product of great commercial interest due to its practicality in production, marketing, and consumption, in addition to having a long commercial life (DIAS et al., 2016).

According to Oliveira et al. (2018), the cookie type cookie is accepted and consumed by people of any age, it has attractive power, especially for children. For these and others, for this reason, biscuits are a viable means of replacing wheat flour with flour from other sources, such as fruit peels.

Some researchers have already been carried out with fruit flours such as: kiwi fruit (SANTOS et al., 2020); japanese quince (ANTONIEWSKA et al., 2019); pineapple peel, mango peel, banana peel, orange peel, watermelon peel and mango almond (RAMOS et al., 2020); guavira (MEDINO et al., 2019); pearl pineapple and ruby passion fruit from the cerrado (ARAUJO et al., 2019); yellow, red aracá, and pitanga (SANTOS et al., 2018).

The technological potential of acerola bark by food industries will be widely explored, since its nutritional and sensory characteristics are peculiar and appreciated for the development of new products, especially the production of flour from its bark. There is research available on the study of the technological potential of various fruits and the development of various food products (SILVA et al., 2019).

In this context, to minimize the loss of raw material and production costs using waste, the present study aims to elaborate different cookie-type cookie formulations with different concentrations of acerola residue flour, in addition to characterizing the elaborated flour and cookies for proximate and physical parameters.

Methodology

The acerolas (*Actinidia delicious*) used were purchased from the local market in the city of Natal, Rio Grande do Norte, Brazil.

Figure 1. Acerola (*Malpighia emarginata* DC) used in the samples.

Obtaining waste

After selection and cleaning of the fruits, they were processed with the aid of a fruit processed, separating the pulp and residue fractions. The residues were used for the development of this work.

Drying of acerola residue

Acerola residues were subjected to convective drying at a temperature of 60°C in an oven with forced air circulation at a speed of 2.0 m s^{-2} until reaching constant mass.

Obtaining acerola residue flour

The grinding of the residues after convective drying was done using an industrial blender in a time of 3 minutes, under agitation. The samples were placed in laminated packages under shelter from light, until the moment of analysis and preparation of cookies, to maintain the properties of the flour.

Determination of proximate composition

The acerola residue flour was characterized according to the following proximate parameters:

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

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

(3) 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).

(4) Lipid content was quantified by the modified method of Blig and Dyer (1959).

(5) Total carbohydrate content was calculated by difference to obtain 100% of the total composition (FAO, 2003).

Physical properties of acerola residue flour

In triplicate the following physical properties of the acerola residue flour were determined:

(1) Bulk density was determined with the aid of a 10 mL beaker previously weighed and then filled with flour, and determined using Equation 1 (TONON et al., 2009).

$$\rho_{ap} = \frac{m}{V} \qquad \text{(Eq.1)}$$

(2) The compacted density was determined from the assembly used in the bulk density, subjecting the beaker filled with the sample to be tapped 50 times on the bench, from a pre-established height of 2.5 cm, calculating the relationship through Equation 2 (TONON et al., 2009).

$$\rho_c = \frac{m}{V_c} \qquad \text{(Eq.2)}$$

(3) The Hausner Factor (FH) which assesses the cohesiveness of the flour, was determined using the Wells methodology (1988), and calculated according to Equation 3.

$$FH = \frac{\rho_C}{\rho_{ap}} \qquad \text{(Eq.3)}$$

(4) The Carr index (CI), which comprises the fluidity index, was determined from the methodology of Wells (1988) and calculated according to Equation 4.

$$IC = \frac{\rho_c - \rho_{ap}}{\rho_{ap}} x100\% \quad \text{(Eq.4)}$$

Cookie biscuit making

Cookies were prepared in 4 formulations, using acerola residue flour, where all the ingredients used are described in Table 1.

Table 1. Formulation for the production of cookie type cookies

Ingredients	Ingredients (g/100g)			
	B1	**B2**	**B3**	**B4**
Wheat flour	100	95	90	85
Acerola residue flour	0	5	10	15
Refined sugar (g)	30	30	30	30
Salt (g)	1	1	1	1
Sodium bicarbonate (g)	0.2	0.2	0.2	0.2
Vegetable fat (g)	50	50	50	50
Corn Starch (g)	14	14	14	14

Note: Flour base percentage.

The mixture of ingredients was carried out using a planetary mixer, the mixing time was 12 min, until obtaining a homogeneous mass. Then, the cookies were molded into a circular shape, being arranged in rectangular shapes. The baking was carried out in a preheated domestic oven at 180°C, for approximately 25 min. After baking, the cookies were packed in hermetic laminated packages.

Characterization of cookies

The four formulations (B1, B2, B3 and B4) of cookies made with acerola residue flour were characterized according to the proximate parameters of water, ash, lipids, proteins and carbohydrates described above. In addition, they were also characterized regarding the parameters of:

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

(2) The firmness of the cookies was evaluated in a universal texturometer model TA-XT plus - Texture Analyzer from the manufacturer Stable Micro Systems, equipped with the Exponent Stable Micro Systems software. The parameters used in the tests were: pre-test speed = 1.0 mm/s, test speed = 3.0 mm/s, post-test speed = 10.0 mm/s, 5.0 mm distance, with measure of force in compression. Firmness results were expressed in newtons (N).

Statistical analysis

The experimental data were analyzed in triplicate and the results were submitted to the analysis of variance of a single factor (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 analysis, the software Assistat 7.7 (SILVA & AZEVEDO, 2016) was used.

Results

In Table 2, the mean values obtained to characterize the proximate composition of the acerola residue flour, dried at 60°C, are presented.

The acerola residue flour had a moisture content of 6.32 g/100g, within the maximum value stipulated by Brazilian legislation (BRASIL, 2005) for flours, which is 15.0 g/100g. Silva and Souza (2017), when dehydrating jamelon residues at 60°C, obtained a moisture content of 10.06 g/100g. The ash content obtained in this study was 3.44g/100g. Moreno (2016), in his studies with mango residue flour, obtained an ash content of 3.42 g/100g, a value close to that obtained in the present study.

Table 2. Proximate composition of acerola residue flour

Parameters (g/100g)	Acerola flour
Moisture	6.32 ± 0.10
Ashes	3.44 ± 0.21
Lipids	1.15 ± 0.34
Proteins	7.01 ± 0.11
Carbohydrates	82.02 ± 0.25

Note: Mean ± Standard deviation.

Also in Table 2, the average value of the lipid and protein content obtained for acerola residue flour is observed, which were 1.15 g/100g and 7.01 g/100g, respectively. Scorsatto et al. (2017), obtained 1.85 g/100g of lipids for eggplant flour. Aquino et al. (2010), observed in their studies 8.88 g/100g of protein in acerola residue flour. Soares et al. (2001) obtained a content of 7.77 g/100g of protein for powdered acerola pulp.

The result obtained in relation to the content of total carbohydrates was relatively high, ranging from 82.02 g/100g, in which the analysis of total carbohydrates includes the total fiber content, showing that the acerola residue flour is a powder with high fiber content. In Table 3, the average values of the physical properties of the acerola residue flour are presented.

Table 3. Physical properties of acerola residue flour

Physical properties	Acerola flour
Bulk density (g/cm^3)	0.241 ± 0.02
Compacted density (g/cm^3)	0.316 ± 0.01
Hausner factor	1.31 ± 0.10
Carr Index (%)	31.12 ± 0.10

Note: Mean ± Standard deviation.

The acerola residue flour showed bulk density of 0.241 g/cm^3 and tap density of 0.316 g/cm^3. Silva et al. (2021) obtained values of 0.320 g/cm^3 for bulk density and 0.476 g/cm^3 for tap density of the freeze-dried jambo powder. According to Cavalcante et al. (2017), the low density values are associated with the low moisture content of the dry residue. A value of 1.31 was obtained for the Hausner factor and 31.12% for the Carr index. Silva et al. (2021), in their study with freeze-dried jambo powder obtained values of 48.75% for the Carr index and 1.48 for the Hausner factor.

According to Aziz et al. (2018) and Alves et al. (2020), the Hausner factor is used to classify powder cohesion, which is a good measure of powder consistency and fluidity, in addition, the authors also report that Carr index (CI) greater than 26% indicate too much compressibility. particles, being poorly fluid when packaged and stored.

Table 4 shows the mean values of the proximate composition (moisture, ash, lipids, proteins and carbohydrates) obtained for the different formulations of cookies made with acerola residue flour, after baking.

Table 4. Proximate composition of cookies made with different concentrations of acerola residue flour, after baking

Parameters	**Formulations**			
	B1	**B2**	**B3**	**B4**
Moisture	$3.78^{c} \pm 0.10$	$4.23^{b} \pm 0.13$	$5.78^{a} \pm 0.09$	$4.66^{b} \pm 0.15$
Ashes	$1.22^{d} \pm 0.05$	$1.85^{c} \pm 0.09$	$2.01^{b} \pm 0.11$	$2.21^{a} \pm 0.08$
Lipids	$16.15^{a} \pm 0.50$	$14.21^{b} \pm 0.68$	$10.89^{c} \pm 0.16$	$9.25^{d} \pm 0.07$
Proteins	$4.45^{d} \pm 0.20$	$5.32^{c} \pm 0.11$	$6.11^{b} \pm 0.21$	$6.99^{a} \pm 0.14$
Carbohydrates	$74.05^{c} \pm 0.15$	$74.39^{c} \pm 0.12$	$75.21^{b} \pm 0.10$	$76.89^{a} \pm 0.11$

Note: Equal superscripted letters on the same line do not differ significantly from each other by Tukey's test at the 5% level.

The moisture content of the prepared cookies ranged from 3.78 g/100g to 5.78 g/100g, showing no correlation with increased concentration of acerola residue flour. Statistically, formulations B2 and B4 did not differ from each other. Santos et al. (2019), when preparing cookies with different concentrations of the kiwi residue flour, they obtained moisture content ranging from 4.40 g/100g to 0.62 g/100g. Dias et al. (2016) obtained moisture content ranging from 2.0 to 4.9% for cookies made with different concentrations of oat.

The ash content showed statistically significant differences between the formulations ranging from 1.22 g/100g to 2.21 g/100g, it was also observed that the increase in the concentration of acerola residue flour promoted an increase in the ash content. Ikechukwu et al. (2018) when preparing cookies with different concentrations of watermelon seed flour, obtained ash content ranging from 1.79 to 4.60 g/100g when the concentration ranged from

20 to 50%. The ash contents found for the cookies under study were still in accordance with the Brazilian food and beverage legislation, whose maximum ash content allowed in cookies is 4.0 g/100g (BRASIL, 1978).

Regarding the lipid content, it was observed that increasing the addition of acerola residue flour by up to 15% reduced the lipid content of cookies by up to 6.90 g/100g. The highest content (16.15 g/100g) was obtained for formulation B1 with 0% acerola residue flour and the lowest content (9.25 g/100g) for formulation with 15% acerola residue flour. Statistically all formulations showed significant differences when compared to each other. Aquino et al. (2010) when they also made cookies with acerola residue flour, the formulation with 10% of the flour presented 10.40 g/100g of lipids.

Differently from what was observed for the lipid content, the protein content increased with the increase in the addition of acerola residue flour, with values ranging from 4.45 g/100g (B1) to 6.99 g/100g (B4). Statistically all formulations showed significant differences when compared to each other. Aquino et al. (2010) when they also made cookies with acerola residue flour, the formulation with 10% of the flour presented 6.78g/100g of protein. Albuquerque et al (2016), obtained 5.56 g/100g of protein in cookies with the addition of seriguela.

The carbohydrate content ranged from 74.05 g/100g (B1) to 76.89 g/100g (B4), with statistical differences only between formulations B3 and B4. Santos et al. (2019) obtained values ranging from 62.10 g/100 to 64.78 g/100 g for cookies with kiwi peel flour and Pereira et al. (2016), obtained values ranging from 70.77 g/100g to 74.69 g/100g for cookies with the addition of Jatobá flour.

Table 5 shows the mean values of firmness (N) obtained for different cookie formulations made with acerola residue flour, after baking.

Table 5. Firmness of the different formulations of cookies made with acerola residue flour, after baking

Formulations	**Firmness (N)**
B1	$13.51^{c} \pm 0.66$
B2	$16.42^{b} \pm 0.24$
B3	$19.74^{a} \pm 0.74$
B4	$20.51^{a} \pm 0.81$

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

Analyzing Table 4, it was found that there were significant changes in the firmness parameter, however the B3 and B4 formulations did not differ at a 5% probability level; The firmness of cookies increased as there was an increase in the concentration of acerola residue flour in its formulation. There was an increase of 7.00 N when the concentration varied up to 15%. The formulation with 15% presented the highest value for this parameter (20.51 N). Values higher than those in the present study were observed by Almeida et al. (2020) who, when determining the texture of cookies made with red rice flour for 60 days, obtained values ranging from 76.54 N to 165.5 N, among the elaborated formulations. Ramos et al. (2020), when preparing cookies with flours from different fruit residues (pineapple peel, mango, banana, orange, watermelon husk and mango almonds), obtained values ranging from 26.22 N to 52.37 N.

According to Carneiro et al. (2011) firmness is the strength needed to achieve a certain deformation in the food. Texture analysis is an important item in the food industry in the control of the manufacturing process, raw materials, final product and research into the development of new products (ALMEIDA et al., 2020). Table 6 shows the mean values of water activity (aw) obtained for different cookie formulations made with acerola residue flour, after baking.

Table 6. Water activity (aw) of different cookie formulations made with acerola residue flour, after fermentation

Formulations	Water activity
B1	$0.098^{c} \pm 0.01$
B2	$0.101^{c} \pm 0.02$
B3	$0.122^{b} \pm 0.00$
B4	$0.150^{a} \pm 0.01$

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

To ensure the shelf life and guarantee the quality of the cookies, it is necessary to have knowledge in relation to the water activity, the elaborated cookies presented low values of water activity, in which only the B3 and B4 formulations present a statistically significant difference. There was a variation from 0.098 to 0.150, the highest value being obtained for formulation (B4) with 15% of the acerola residue flour. Miranda et al. (2021), when developing gluten-free cookies enriched with orange residue flour, obtained values from 0.39 to 0.49. According to Almeida et al. (2020) water activities between 0.30 and 0.40, at room temperature, are sufficient to cause structural changes, such as lumping of powders and loss of crispness and fracturability in biscuits.

Conclusion

Based on the results obtained, we can conclude that:

The drying process reduced the moisture content of the acerola residue, which could be stored and used for a longer period. Furthermore, the acerola residue flour had good protein content and increased carbohydrate content. Regarding its physical properties, the flour had low densities and good flow characteristics.

The use of acerola residue flour in the preparation of cookies reduced the lipid content and increased the ash and protein content. The formulation with 15% (B4) of the flour showed greater firmness and all formulations had low values of water activity ($a_w < 0.16$).

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Chapter V

PREPARATION OF ACEROLA (*Malpighia emarginata* DC) JELLIES: INFLUENCE OF PULP PERCENTAGE ON CENTAGE COMPOSITION, BIOACTIVE COMPOUNDS AND TEXTURE

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Introduction

One of the main characteristics of the industrial and artisanal production of jams is to add value to raw materials, both from large and small producers, thus alleviating the problems of lack of supply for consumers. The jellies emerged with the aim of making the fruits available during the off-season, as stable products on the shelves, in addition, it is an alternative to minimize the waste caused by the perishability of the fruits (SOUZA et al., 2021).

According to the Brazilian legislation on fruit jams, represented by Resolution No. 12 of July 24, 1978, and Normative Resolution No. 15 of May 4, 1978, this product can be classified as extra jelly, simple jelly and premium jelly. Common and extra jellies can still be classified as "simple" (non-mandatory term), when prepared with a single type of vegetable, or "mixed" (optional term) when prepared with two or more vegetable species.

Mixed jellies are important alternatives, as they combine nutritional characteristics of two or more fruits, in addition to providing pleasant sensory characteristics, and have been gradually conquering a prime position in the consumer market (BRASIL, 1978).

Some researchers have already used fruits for the preparation of jams such as strawberries (SILVA et al., 2021); umbu-cajá (SANTOS et al., 2021); pitaya (MIRANDA et al., 2020); guabiroba (PEREIRA et al., 2020); grape and passion fruit (NASCIMENTO et al., 2020); banana (BORGES et al., 2011).

Acerola is a fruit known as an excellent food source of vitamin C, it also contains bioactive compounds in its composition (SAQUETI et al., 2021). The red color of acerola, in the mature stage, is due to the presence of anthocyanins. These pigments are phenolic compounds, soluble in water, belonging to the group of flavonoids, widely diffused in the plant kingdom, which give fruits, flowers and roots the color nuances between orange and red (LIMA et al., 2003).

According to Nascimento et al. (2018), the processing of acerola consists of obtaining products such as pulps, juices, concentrates, sweets, compounds and jellies, with appropriate technology for each processing. These products are important in the agroindustrial activity, as they value the fruits, avoid waste and reduce losses from the sale of fresh fruit. In this context, the present study aims to prepare jellies with different concentrations of acerola pulp and characterize them in terms of proximate parameters, bioactives and texture profile.

Methodology

The acerolas (*Actinidia delicious*) used were purchased from the local market in the city of Natal, Rio Grande do Norte, Brazil.

Figure 1. Acerola (*Malpighia emarginata* DC) used in the samples.

Obtaining the pulp

After selection and cleaning of the fruits, they were processed with the aid of a fruit processed, separating the pulp and residue fractions. The residues were used for the development of this work.

Determination of proximate composition

Acerola pulp was characterized according to the following proximate parameters:

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

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

(3) 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).

(4) lipid content was quantified by the modified method of Blig and Dyer (1959).

(5) total carbohydrate content was calculated by difference to obtain 100% of the total composition (FAO, 2003).

Determination of bioactive compounds

Vitamin C content was determined by the reaction of ascorbic acid with 2,6-dichlorophenol indophenol (DCFI), as described by Brasil (2008), and the results were expressed in mg ascorbic acid/100g sample. The total anthocyanin content was determined following the unique pH method described by Francis (1982).

Preparation of the jelly

Four formulations of acerola jellies (G1, G2, G3 and G4) were prepared with different concentrations of acerola pulp. In Table 1, the ingredients with their respective concentrations and amounts used for the development of the jelly can be seen.

Table 1. Concentrations and amounts of ingredients used to prepare acerola jelly

Formulations	**Acerola pulp (%)**	**Pectin (g)**	**Sugar (g)**	**Water (%)**
G1	10	10	250	90
G2	20	10	250	80
G3	30	10	250	70
G4	40	10	250	60

Method of preparation

All the ingredients were mixed in a stainless steel pan, with the pectin being previously mixed with the sugar in order not to form globules in the jelly, given its difficult homogenization; the mixture of ingredients was subjected to cooking at atmospheric pressure with manual stirring over a low heat until a jelly texture with a total soluble solids content of around 65 °Brix was obtained, following the same procedures adopted by Moura et al. (2020). After this step, each formulation was filled in previously sterilized glass containers and stored under refrigeration

Characterization of jellies

The four formulations of jellies made with acerola pulp were characterized according to the proximate parameters of water, ash, lipids, proteins and carbohydrates and bioactive compounds (vitamin C and anthocyanins) described above. In addition, they were also characterized regarding the parameters of:

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

(2) The firmness of the cookies was evaluated in a universal texturometer model TA-XT plus - Texture Analyzer from the manufacturer Stable Micro Systems, equipped with the Exponent Stable Micro Systems software. The parameters used in the tests were: pre-test speed = 1.0 mm/s, test speed = 3.0 mm/s, post-test speed = 10.0 mm/s, 5.0 mm distance, with measure of force in compression. Firmness results were expressed in newtons (N).

Statistical analysis

The experimental data were analyzed in triplicate and the results were submitted to the analysis of variance of a single factor (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 analysis, the software Assistat 7.7 (SILVA & AZEVEDO, 2016) was used.

Results

Table 2 shows the mean values obtained for the proximate composition of the acerola pulp.

Table 2. Proximate composition of acerola pulp

Parameters (g/100g)	**acerola pulp**
Moisture	90.78 ± 0.28
Ashes	0.31 ± 0.01
Lipids	0.87 ± 0.14
Proteins	1.41 ± 0.61
Carbohydrates	6.63 ± 0.39

Note: Mean ± Standard deviation.

Based on the results obtained for the proximate composition of the acerola pulp, it is noticeable that it has a high moisture content (90.78 g/100g), thus evidencing its susceptibility to the development of microorganisms and the biochemical reactions responsible for its degradation. Amadeu et al. (2020), obtained 91.79 g/100g of moisture for refined frog skin melon pulp.

For the parameters of ash and lipids, mean values of 0.31 g/100g and 0.87g/100g were obtained, respectively. Ash content higher than in the present study was obtained by Reis et al. (2020) for melon pulp (0.50 g/100g). According to Instituto Adolfo Lutz (BRASIL, 2008), the lipid content in fruits can vary from 0.1 to 1g/100g. Acerola pulp presented 0.87 g/100g of lipids, being within this range. Moura et al. (2019), obtained a lipid content of 0.17 g100g for passion fruit pulp.

The protein content obtained was 1.41 g/100g. Higher values were observed by Nascimento et al. (2018) for handmade acerola pulp (2.25 g/100g) and industrially produced (2.71 g/100g). Regarding the carbohydrate content, a value of 6.63 g/100g was obtained. Table 3 shows the mean values obtained for bioactive compounds (vitamin C and total anthocyanins) from acerola pulp.

Table 3. Determination of bioactive compounds from acerola Pulp

Parameters	**Acerola pulp**
Vitamin C (mg/100g)	958.74 ± 6.24
Anthocyanins (mg/100g)	39.22 ± 1.37

Note: Mean ± Standard deviation.

Acerola pulp showed a high concentration of ascorbic acid 958.74 mg/100g. Values close to those of the present study were obtained by Caetano et al. (2012), who obtained 1054 mg/100g for acerola pulp and by Nascimento et al. (2018), who obtained 633.04 mg/100g for artisanal acerola pulp and 1080.11 mg/100g for industrial acerola pulp. Regarding the anthocyanin content, an average value of 39.22 mg/100g was quantified. Values close to those of the present study were determined by Lima et al. (2003), in which they obtained anthocyanin values ranging from 3.79 mg/100g to 59.74 mg/100g.

In Table 4, it is possible to observe the average values of the moisture content of the different formulations of jellies made with acerola pulp.

Table 4. Moisture content of different jellies formulations made with acerola pulp

Formulations	**Humidity (g/100g)**
G1	$29.65^{d} \pm 0.66$
G2	$32.55^{c} \pm 0.19$
G3	$34.34^{b} \pm 0.20$
G4	$36.79^{a} \pm 0.17$

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The moisture content showed an increase in its values from 29.69 g/100g to 36.79 g/100g when there was an increase in the concentration of acerola pulp from 10 to 40%. All formulations showed statistically significant differences when compared to each other.

It can also be said that the moisture content values obtained are in accordance with the quality standard established by Brazilian legislation (BRASIL, 1978), which indicates that the maximum moisture content for fruit jellies should be lower. to 38%. Values close to those of the present study were observed by Bú et al. (2021) in their studies with different formulations of peppermint jelly enriched with spirulina that obtained moisture content ranging from 31.92 g/100g to 37.32 g/100g. Caetano et al. (2012) when preparing jams with acerola pulp and juice, obtained contents ranging from 29.79 g/100g to 32.56 g/100g.

According to Viana et al. (2012), it is important to highlight that the moisture content is directly related to the conservation of the product during its storage. In Table 5, it is possible to observe the average values of the ash content of the different formulations of jellies made with acerola pulp.

Table 5. Ash content of different formulations of jellies made with acerola pulp

Formulations	Ash (g/100g)
G1	0.31[a] ± 0.01
G2	0.32 [a] ± 0.05
G3	0.37 [a] ± 0.02
G4	0.39 [a] ± 0.01

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The average values obtained for the ash content of the different formulations did not show statistically significant differences between them. However, it is possible to observe an increase in their values when there was an increase in the pulp concentration. The highest content (0.39 g/100g) was obtained for formulation G4 with 40% acerola pulp and the lowest content (0.31 g/100g) for formulation G1 with 10% acerola pulp. Low ash contents were also reported by Oliveira et al. (2019) when preparing achachairu jelly, in which they observed values between 0.28 and 0.80 g/100g. Morais et al. (2021), obtained 0.16 g/100g for acerola jelly, 0.20 g/100g for strawberry jelly and 0.23 g/100g for acerola and strawberry jelly. According to Khan et al. (2014) the ash content depends on the type of soil in which the fruit tree is grown and its composition.

Table 6 shows the mean values of the lipid content of the different jellies formulations made with acerola pulp.

Table 6. Lipid content of different formulations of jellies made with acerola pulp

Formulations	Lipids (g/100g)
G1	0.16 [c] ± 0.05
G2	0.29 [b] ± 0.02
G3	0.34 [a] ± 0.01
G4	0.36 [a] ± 0.04

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

As for the lipid content, the jellies showed low values, between 0.16 g/100g (G1) and 0.36 g/100g (G4). The G3 and G4 jellies did not show statistical differences between the mean values obtained. Low values were also observed by Souza et al. (2015) when preparing blackberry jellies with lipid content ranging from 0.09 to 0.15 g/100g. Barros et al. (2019a), obtained values ranging from 0.17 g/100g to 0.37 g/100g for different formulations of kiwi jelly with capim santo. Barros et al. (2019b), when preparing pineapple jams with cinnamon in different types of sugar, they obtained low levels ranging from 0.15 to 0.49 g/100g. In Table 7, it is possible to observe the mean values of the protein content of the different formulations of jellies made with acerola pulp.

Table 7. Protein content of different formulations of jams made with acerola pulp

Formulations	**Proteins (g/100g)**
G1	0.20 ^{a} ± 0.05
G2	0.23 ^{a} ± 0.01
G3	0.24 ^{a} ± 0.04
G4	0.25 ^{a} ± 0.02

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

Regarding the mean values of proteins obtained for the different formulations, it was observed that there were no statistically significant differences when the formulations were compared to each other. Protein contents ranged from 0.20 to 0.25 g/100g, and this increase was correlated with an increase in acerola pulp concentration from 10 to 40%. Values higher than those in the present study were obtained by Bú et al. (2021) for spurilina-enriched mint jellies, which ranged from 0.73 to 8.35g/100g. In Table 8, it is possible to observe the mean values of the carbohydrate content of the different jellies formulations made with acerola pulp.

Table 8. Carbohydrate content of different formulations of jams made with acerola pulp

Formulations	**Carbohydrates (g/100g)**
G1	69.63 ^{a} ± 0.16
G2	66.61 ^{b} ± 0.14
G3	64.71 ^{c} ± 0.21
G4	62.21 ^{d} ± 0.18

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The carbohydrate content of the jellies ranged from 62.21 g/100g to 69.63 g/100g, it was possible to observe a reduction in the mean values of this parameter when there was an increase in the percentage of pulp in the formulations. Statistically, the four formulations, when compared to each other, showed significant differences for the Tukey test. Values lower than those in the present study were observed by Nascimento et al. (2020) in their studies with mixed grape and passion fruit jellies, obtained carbohydrate contents of 24.6 g/100g for traditional jam, 14.7 g/100g for light jam and 4.0 g/100g for diet jam. Table 9 shows the mean values obtained for vitamin C from the different formulations of jams made with acerola pulp.

Table 9. Vitamin C content of different formulations of jams made with acerola pulp

Formulations	**Vitamin C (mg/100g)**
G1	369.47 ^{d} ± 6.54
G2	431.98 ^{c} ± 4.01
G3	517.59 ^{b} ± 3.11
G4	624.10 ^{a} ± 2.86

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The ascorbic acid (vitamin C) contents of the formulations differed statistically from each other, reaching the highest value of 624.10 mg/100g for the G4 formulation with 40% acerola pulp. Caetano et al. (2012), obtained values ranging from 599.25 to 664.79 mg/100g for jelly made with acerola juice and pulp. Vitamin C or ascorbic acid is the best known micronutrient of the vitamin group. It is water-soluble and thermolabile, in addition to performing several important biological functions, among them, it acts as an important antioxidant, increasing the number of antibodies and acting on the differentiation and proliferation of immune system cells (BERGMANN, 2021).

Table 10 shows the mean values obtained for the total anthocyanin content of the different formulations of jams made with acerola pulp.

Table 10. Total anthocyanin content of different formulations of jams made with acerola pulp

Formulations	Anthocyanins (mg/100g)
G1	1.53 [c] ± 0.09
G2	1.89 [c] ± 0.11
G3	2.87 [b] ± 0.04
G4	3.74 [a] ± 0.19

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The content of total anthocyanins showed average values ranging from 1.53 to 3.74 mg/100g, with an increase in values when there was an increase in the concentration of acerola pulp. All formulations showed statistically significant differences among themselves for the Tukey test at the 5% level. The highest value obtained (3.74 mg/100g) was for formulation G4 with 40% acerola pulp. Lemos et al. (2019) obtained values ranging from 2.92 to 6.79 mg/100g for mixed acerola jelly with jabuticaba. Moura et al. (2019) obtained values from 1.04 to 1.94 mg/100g for passion fruit jellies made with different concentrations of flaxseed and Amadeu et al. (2020) obtained values ranging from 0.05 to 0.24 mg/100g for jelly with melon pulp.

According to Morais et al. (2016) anthocyanins are associated with a favorable modulation of the microbiota and inflammatory markers, in addition to having a protective effect against neurodegenerative and chronic diseases, and act as inhibitors of mutagenesis and carcinogenesis, due to their antioxidant power. Table 11 shows the mean values obtained for the water activity (aw) of the different formulations of jams made with acerola pulp.

Table 11. Water activity (aw) of different jellies formulations made with acerola pulp

Formulations	Water activity
G1	0.704 [d] ± 0.00
G2	0.715 [c] ± 0.01
G3	0.795 [b] ± 0.01
G4	0.801 [a] ± 0.00

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

High water activity values were observed, ranging from 0.704 (G1) to 0.801 (G4). Statistically, the formulations when compared to each other showed significant differences for the Tukey test. High values were also observed by Barros et al. (2019b), for pineapple jam with cinnamon (0.638 to 0.885), by Lemos et al. (2019), for jellies made with acerola and jabuticaba pulp (0.713 to 0.795) and by Barrosso et al. (2020), for jellies with biribiri pulp with different concentrations of pectin (0.77 to 0.81).

According to Barros et al. (2019b), reduced moisture content and water activity values indicate greater stability of the product during storage and foods that have a moisture content greater than 20% and water activity greater than 0.60 are subject to deterioration processes caused by molds and yeasts. Table 12 shows the mean values obtained for the texture (Firmness (N)) of the different formulations of jams made with acerola pulp. Texture is an important attribute in the perception and acceptability of the quality of a product, being a reflection of the chemical composition of the food and its structure (BRANDÃO et al., 2020).

Table 12. Firmness of different formulations of jams made with acerola pulp

Formulations	**Firmness (N)**
G1	$0.285^{c} \pm 0.66$
G2	$0.315^{b} \pm 0.24$
G3	$0.421^{a} \pm 0.74$
G4	$0.540^{a} \pm 0.81$

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

It is observed in Table 12 that the firmness parameter varies from 0.285 to 0.540 N, with the highest value obtained for the formulation (G4) which has 40% acerola pulp. Statistically, the G3 and G4 formulations did not show significant differences between them. Barros et al. (2020), when preparing jams with strawberry, pepper and maltodextrin, obtained values ranging from 0.316 to 0.376 N. Lemos et al. (2019), when preparing mixed jabuticaba and acerola jam, obtained values ranging from 0.95 to 4.60 N. Barros et al (2019b), obtained values from 0.216 to 0.263 N for kiwi jams with capim santo tea and Barroso et al. (2020) obtained values from 0.70 to 1.57 N for biribiri jellies with different concentrations of pectin. According to Garrido et al. (2015), firmness is defined as the force required to achieve a given deformation, in the context of sensory analysis, it represents the force required to compress the food between the molars in the first bite.

Conclusion

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

Acerola pulp had a high moisture content, evidencing the need for its processing, in addition, the pulp also presented high values of vitamin C and low concentrations of ash, lipids and proteins.

The parameters analyzed in the prepared jellies showed statistically significant differences with an increase in pulp concentration from 10 to 40%. The G4 formulation, in which it contained the highest percentage of pulp, is the most suitable for industrial development, as it presented higher levels of vitamin C and total anthocyanins.

Acerola pulp is an excellent alternative for making jellies, as it is an easily accessible, low-cost fruit with good acceptability and quality.

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Chapter VI

OBTAINING AND ELABORATION OF CEREAL BAR WITH POWDERED ACEROLA (*Malpighia emarginata DC*) PULP

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Introduction

The demand for nutritious and safe foods has been growing rapidly, mainly due to the dissemination that the intake of balanced foods is the correct way to avoid or even correct health problems, which are largely due to dietary errors. Cereal bars respond to this trend and are made from a mixture of cereals with a pleasant taste. These products are sources of vitamins, minerals, fiber, proteins, and carbohydrates (SILVA et al., 2011).

The cereal bar was introduced in food over a decade ago as an alternative for those consumers who already had a greater awareness of the importance of having a healthier life. The development of these products initially aimed to satisfy the needs of the consumer population that sought pleasure and convenience, as was the case with the consumption of cookies and candy bars, although these were seen as unhealthy products (OLIVEIRA et al., 2020).

In this sense, cereal bars are mainly produced from grains, such as rice and oats, and can be enriched with proteins from whey, for example. The flavoring base of these bars originally tends to the chocolate flavor, however, currently there is a trend towards nutritional enrichment of this food using other products such as oilseeds, herbs and fruit flours. Fruit and vegetable flours can be used as raw material, due to their functional and technological properties, which enable an improvement in the physicochemical quality, viscosity, texture and nutritional value of the final product (BCHIR et al., 2018). They are widely consumed as a source of proteins and bioactive compounds, providing practical and healthy energy for everyday life (KAUR et al., 2018).

An acerola (*Malpighia emarginata* D.C.) represents a strategic food matrix with potential for the food industry due to the possibility of developing products with high quality and high nutritional value. Thus, the development of new products using powdered fruit pulp, in addition to innovating with nutritious ingredients, gives the product other attributes such as color, appearance, flavor and texture. Such foods have characteristics such as antioxidant, anti-inflammatory, anticancer activity, among others, due to phytochemicals or bioactive compounds naturally present in them (RODRIGUES, 2013).

Chang et al. (2019), classify acerola in the superfruit group, due to the high concentration of phytochemicals such as phenolic acids, flavonoids, proanthocyanidins, iridoids, coumarins, hydrolyzable tannins, carotenoids and anthocyanins, which together with their antioxidant activities represent a valuable source for the development of functional foods.

Bourekoua et al. (2021) in one of their most recent researches found that the enrichment of gluten-free breads made with rice flour and acerola powder improved the antioxidant properties with a significant increase in the total phenolic content, in addition to the acerola powder positively affected the parameters, criteria, textures, sensory among others.

In this context, the present study aims to develop different formulations of cereal bars with different percentages of powdered acerola pulp and characterize the formulations made in relation to proximate composition, characteristics, and firmness.

Methodology

The acerolas (*Actinidia delicious*) used were purchased from the local market in the city of Natal, Rio Grande do Norte, Brazil.

Figure 1. Figure 1. Acerola (*Malpighia emarginata* DC).

Initially, acerola went through the steps of cleaning, sanitizing, sanitizing in a sodium hypochlorite solution (200 mg L^{-1} of free chlorine) for 15 min and washing in running water. Then, with the aid of a domestic blender, without adding water, the fruits were processed, and their pulp was obtained.

Obtaining acerola powder

Acerola powder was obtained through the foam layer drying process. For this, acerola pulp, skimmed milk powder, neutral alloy and Emustab were used. All ingredients were mixed using a domestic mixer during (20 min) of agitation, using its maximum speed, after which time the foam was obtained and subjected to convective drying in a fixed air circulation oven with speed of 1.0 m s^{-1} at a temperature of 70°C.

Preparation and preparation of the cereal bar

The cereal bars were prepared in four different formulations: (B1) standard (no acerola powder added), (B2) adding 20%, (B3) adding 40%, and (B4) 60% of acerola powder.

The other ingredients used were oat flakes, rice flakes, raisins, corn glucose, water, soy lectin and guar gum.

The ingredients were weighed separately, the soy lectin was dissolved in water and then mixed with the other ingredients. Subsequently, cooking was carried out in a stainless-steel pan at a temperature of 90°C until obtaining a homogeneous mass. The hot mass was shaped into an aluminum shape, remaining until cooled. Then, the bars were cut and individually conditioned in flexible film packages, stored in a dry and ventilated place and at room temperature.

Characterization of the bars

The four formulations developed were characterized in terms of the following parameters:

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

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

(3) 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).

(4) Lipid content was quantified by the modified method of Blig and Dyer (1959).

(5) Total carbohydrate content was calculated by difference to obtain 100% of the total composition (FAO, 2003).

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

(7) The firmness of the cookies was evaluated in a universal texturometer model TA-XT plus - Texture Analyzer from the manufacturer Stable Micro Systems, equipped with the Exponent Stable Micro Systems software. The parameters used in the tests were: pre-test speed = 1.0 mm/s, test speed = 3.0 mm/s, post-test speed = 10.0 mm/s, 5.0 mm distance, with measure of force in compression. Firmness results were expressed in newtons (N).

(8) pH was determined through direct reading on the digital pH meter (BRASIL, 2008).

Statistical analysis

The experimental data were analyzed in triplicate and the results were submitted to the Tukey test, adopting the 5% level of significance. For the development of statistical analysis, the software Assistat 7.7 (SILVA & AZEVEDO, 2016) was used.

Results

In Table 1, it is possible to observe the average values of the moisture content of the different cereal bars made with powdered acerola pulp.

Table 1. Moisture content of different cereal bar formulations made with powdered acerola pulp

Formulations	**Moisture (g/100g)**
B1	11,21 ± 0,06[c]
B2	10,54 ± 0,11[b]
B3	12,78 ± 0,16[a]
B4	10,98 ± 0,04[b]

Note: Equal letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The water content of the cereal bars ranged from 10.54 to 12.78 g/100g, the highest value being obtained for formulation B3 which contains 40% of the powdered acerola pulp. Formulations B2 (20%) and B4 (60%) did not show statistically significant differences at the 5% probability level. According to Costa et al. (2005), these results can positively contribute to the quality and stability of formulated bars.

Lima et al. (2021) when developing different formulations of cereal bars with co-products of cashew stalk and whey, obtained values close to those of the present study, ranging from 9.90 to 11.0 g/100g. Higher values were observed by Cardoso et al. (2014) in cereal bars with the addition of pequi peel flour, which ranged from 20.84 to 23.67 g/100g.

In Table 2, it is possible to observe the average values of the ash content of the different cereal bars made with powdered acerola pulp.

Table 2. Ash content of different formulations of cereal bars made with powdered acerola pulp

Formulations	**Ashes (g/100g)**
B1	1,07 ± 0,14^{d}
B2	1,64 ± 0,10^{c}
B3	1,89 ± 0,06^{b}
B4	2,54 ± 0,04^{a}

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

Regarding the ash content, there was a tendency to increase this parameter by increasing the percentage of acerola pulp powder. Values ranging from 1.07 to 2.54 g/100g were obtained and all samples showed statistically significant differences when compared to each other.

According to Lima et al. (2010) cereals must have total ash content between 0.3 and 3.3 g/100, so the ash content of the bars elaborated in this study showed the expected ash content. Vieira et al. (2019) when preparing different formulations of cereal bars with mixed flour of pineapple and cashew residues, obtained ash contents ranging from 1.76 to 2.82 g/100g. Fonseca et al. (2011) when preparing cereal bar with pineapple peel, they obtained ash content of 1.17 g/100g.

Table 3 shows the mean values of the lipid content of different cereal bars made with powdered acerola pulp.

Table 3. Lipid content of different cereal bar formulations made with powdered acerola pulp

Formulations	**Lipids (g/100g)**
B1	14,69 ± 0,20^{a}
B2	13,10 ± 0,16^{b}
B3	12,93 ± 0,04^{bc}
B4	12,71 ± 0,11^{c}

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

When determining the lipid content, there was a variation from 12.71 to 14.69 g/100g, with a noticeable reduction in the values of this parameter when there was an increase in the concentration of acerola pulp powder from 20% to 60%. The highest lipid content was obtained for standard formulation (B1), which did not contain acerola pulp powder in its composition. Statistically, formulation B3 with 40% of acerola pulp powder did not show significant differences when compared to formulations B2 and B4.

Values lower than the present study were reported by Araújo et al. (2021) when preparing cereal bars added with whole cowpea, cashew nut and banana flour, in which the values ranged from 7.66 to 8.66 g/100g. According to Roberto et al. (2015), the lipid is the constituent with the highest amount of calories, a fact that is not desirable in foods that have functional appeal.

In Table 4, it is possible to observe the mean values of the protein content of the different cereal bars made with powdered acerola pulp. According to Fonseca et al. (2011) proteins are essential nutrients for human nutrition, as they play very important roles in the body, such as assisting in tissue construction and in the formation of enzymes, such as digestive enzymes and hormones, such as insulin.

Table 4. Protein content of different cereal bar formulations made with powdered acerola pulp

Formulations	**Proteins (g/100g)**
B1	2,01 ± 0,01^{c}
B2	3,19 ± 0,06^{b}
B3	3,63 ± 0,03^{ab}
B4	3,91 ± 0,10^{a}

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

An increase in protein content was observed due to the increase in the percentage of acerola pulp powder used in the formulations, with a variation of 2.01 to 3.91 g/100g. Statistically, formulation B3 with 40% of acerola pulp powder did not show significant differences when compared to formulations B2 and B4. Bueno et al. (2020) when preparing cereal bars with grape and jabuticaba residues, they obtained protein contents ranging from 0.43 to 0.76 g/100g. Appelt et al. (2015) when developing cereal bars with the addition of jabuticaba residue flour, found protein content between 8.9 to 9.2 g/100g. Table 5 shows the mean values of carbohydrate content of different cereal bars made with powdered acerola pulp.

Table 5. Carbohydrate content of different cereal bar formulations made with powdered acerola pulp

Formulations	Carbohydrates (g/100g)
B1	71,02 ± 0,14[a]
B2	71,53 ± 0,09[a]
B3	68,77 ± 0,21[b]
B4	69,86 ± 0,13[c]

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

With the analysis of the macronutrients that make up the formulation, it is known that, in most studies, carbohydrates are present in higher concentrations in the centesimal composition of foods, especially in cereal-based products (ALEIXO et al., 2021). Thus, the carbohydrate content of the elaborated bars was the constituent present in the highest concentration, ranging from 68.77 to 71.53 g/100g. Statistically, formulations B1 and B2 did not show significant differences when compared to each other. Values higher than those in the present study were reported by Bueno et al. (2020) ranging from 82.93 to 84.33 g/100g and by Lima et al. (2021) ranging from 57.70 to 58.50 g/100g, these differences may be related to the different ingredients used in the formulations. Table 6 shows the mean values of water activity (aw) of the different cereal bars made with powdered acerola pulp.

Table 6. Water activity (aw) of the different formulations of cereal bars made with powdered acerola pulp

Formulations	Water activity
B1	0,60 ± 0,01[a]
B2	0,61 ± 0,03[a]
B3	0,63 ± 0,02[a]
B4	0,70 ± 0,01[a]

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

There was no significant difference ($p > 0.05$) between the formulations regarding water activity, which presented values from 0.60 to 0.60. Our findings corroborate the literature. Bueno et al. (2020) when preparing cereal bars with grape and jabuticaba residues, they obtained water activity values between 0.568 and 0.690. For any type of bacteria, the minimum water activity value required for growth is 0.75 (halophilic bacteria), while osmophilic yeasts and xerophilic fungi are able to develop in water activity of 0.61 and 0 .65 (BUENO et al., 2020).

In Table 7, it is possible to observe the mean values of firmness (N) of the different cereal bars made with powdered acerola pulp. According to the ISO Standard (1992), texture is the set of mechanical, geometric and surface properties of a product, detectable by mechanical and tactile receptors and, possibly by visual and auditory receptors, being a relevant parameter with regard to production of cereal bars.

Table 7. Firmness of the different formulations of cereal bars made with powdered acerola pulp

Formulations	Firmness (N)
B1	29,70 ± 0,54[a]
B2	26,12 ± 0,87[d]
B3	28,94 ± 0,69[b]
B4	27,88 ± 0,74[c]

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The firmness parameter presented values ranging from 26.12 to 29.70 N. Statistically all the elaborated formulations showed significant differences between them ($p > 0.05$). Values close to those obtained in the present study were reported by Rodrigues et al. (2018) when preparing cereal bars with cashew bagasse, where the firmness of the bars ranged from 26.644 N to 37.857 N. Values ranging from 12 to 19 N were found by Damasceno et al. (2017), on the use of Spirulina platensis biomass for cereal bar enrichment. Table 8 shows the mean pH values of different cereal bars made with powdered acerola pulp.

Table 8. pH of different formulations of cereal bars made with powdered acerola pulp

Formulations	pH
B1	6,33 ± 0,01ª
B2	6,15 ± 0,02ª
B3	6,00 ± 0,01[ab]
B4	5,98 ± 0,01[b]

Note: Equal superscripted letters in the same column do not differ significantly from each other by Tukey's test at the 5% level.

The pH values of the cereal bars were shown to be low acid, with values ranging from 5.98 to 6.33, indicating a product not susceptible to microbiological attack, with (6.5-7.0) the pH range being more favorable for most microorganisms. Statistically formulation B4 differs significantly from B1 and B2 ($p > 0.05$). Silva et al. (2014) observed pH from 6.12 to 6.41 in cereal bars using soy extract residue. Vieira et al. (2019) observed pH from 5.91 to 6.54 in cereal bars made with cashew and pineapple residues. According to Dias et al. (2020) the pH is a very important factor in food preservation, as it limits the development of microorganisms.

Conclusion

The elaboration of cereal bars with powdered acerola pulp was viable and presented itself as an excellent alternative for the nutritional enrichment of a product already on the market.

Furthermore, they presented good values of water content and water activity and were classified as low acid.

As suggestions for future work, microbiological analysis, sensory analysis, purchase intention and a stability study during the storage of the different elaborated bars can be carried out.

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The year 2021 is the International Year of Fruits and Vegetables decreed by the United Nations (UN), promoting the importance of fruits and vegetables for people's health, in addition to promoting actions to prevent food waste. In addition, the Food Systems Summit held in New York, convened by the Secretary General of the United Nations, António Guterres, signed an alignment in the context of the Decade of Action to Achieve the Sustainable Development Goals by 2030, hitherto hampered by the pandemic of COVID 19 worldwide. Thus, this work represents a contribution to the country in meeting the goals of sustainable development in promoting sustainable agriculture and efficient agrifood systems. Most fruit-related research is for subtropical and cold areas. Thus, we prioritized in this work a tropical and exotic fruit, the acerola (*Malpighia emarginata DC*). Tropical fruits have nutritional importance for several countries, due to their wide applicability in the development of new products obtained from their processing. Fruit growing is one of the fundamental sectors, especially in tropical countries like Brazil. Acerola (*Malpighia emarginata DC*) is defined worldwide as a superfruit for its high concentration of ascorbic acid, one of the most important water-soluble vitamins. In addition to provitamin A, vitamins B1 and B2. The fruit has a range of phytonutrients such as phenolics, flavonoids, anthocyanins and carotenoids. Regarding the extract, many studies have shown that the antioxidant activity of acerola extract is much higher compared to polyphenol-rich extracts from other fruits. Thus, we gather in one work the most relevant researches for the growth and development of new products and production chains with the techniques of processing, drying, thermophysical properties, mathematical modeling, among others. We hope that this work will be an application tool, contributing each increasingly to Brazil's innovative potential.

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978-65-00-33220-9