

Optimization of green PLE method applied for the recovery of antioxidant compounds from buriti (*Mauritia flexuosa* L.) shell

Adenilson Renato Rudke^a, Simone Mazzutti^a, Kátia Suzana Andrade^a, Luciano Vitali^b,
Sandra Regina Salvador Ferreira^{a,*}

^a Laboratory of Thermodynamic and Supercritical Technologies (LATESC), Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900 Florianópolis, SC, Brazil

^b Department of Chemistry, Federal University of Santa Catarina, Florianópolis, SC, Brazil

ARTICLE INFO

Keywords:

Antioxidants recovery
High pressure extraction
Optimization
Response surface methodology

ABSTRACT

Buriti fruit, with high content in carotenoids and antioxidant compounds, is well appreciated for its organoleptic characteristics. However, its shell, an agroindustrial residue, is mostly discarded. Therefore, to verify the technological potential of the buriti shells, the aim of this study was to evaluate the antioxidant potential of the extracts from buriti shell obtained by pressurized liquid extraction (PLE) with ethanol/water mixtures. PLE optimization was performed by response surface methodology, with all results maximized at the conditions of 71.21 °C and with 91.58% of ethanol. The yields values varied from 16.82 to 25.16%, total carotenoids from 23.38 to 1056.59 µg β-carotene equivalent g⁻¹, total phenolic content from 143.37 to 172.02 mg Gallic acid equivalent g⁻¹, DPPH from 31.04 to 48.62 µg.mL⁻¹, and ABTS from 1.87 to 2.70 mmol TEAC. g⁻¹. Therefore, considering the lack of studies about buriti shell, the present work provides valuable results that confirm the PLE relevance to enhance the value of this neglected material.

1. Introduction

Considered the most abundant palm tree of Brazil, the “*Mauritia flexuosa*”, popularly known as buriti, belongs to the *Arecaceae* family (Koolen, Silva, da Silva, da Paz, & Bataglion, 2018). Buriti tree is present in at least 7 Latin American countries and the Amazonia natives called it “*Tree of Life*” because all its parts have many purposes (Pezoti Junior et al., 2014). This specie grows in flooded areas known as “buritizais” and is food source for several species of animals (Koolen, Silva, Gozzo, De Souza, & De Souza, 2013).

The fruit is considered a functional food because it is an important source of carotenoids, rich in vitamins, antioxidants, unsaturated oils and dietary fibers (Cândido, Silva, & Agostini-Costa, 2015). Several biological benefits for humans (Bataglion, da Silva, Eberlin, & Koolen, 2014), like potent vermifuge and burn healer (Koolen et al., 2018), effective in treatment and prevention of xerophthalmia (Mariath, Lima, & Santos, 1989), and antimicrobial activity (Koolen et al., 2013) are related to buriti. Its pulp, rich in β-carotene, tocopherols, and oleic acid, is resistant to oxidation and comparable to olives (Vásquez-Ocmín, Alvarado, Solís, Torres, & Mancini-Filho, 2010).

The above cited characteristics make buriti an important matrix that can be applied in cosmetic and food industries, mainly due to the pulp

oil (Koolen et al., 2018). However, the pulp only corresponds to 18–30% of the total fruit weight (Barbosa, Lima, & Mourão Junior, 2010), providing 70–82% of poorly used fruit parts, or residue. The shell, for example, is used as animal feed or, not often, as raw material for oil extraction. However, the buriti shell is normally treated as waste, with no proper disposal (Barbosa et al., 2010). About 2500 tons/year of buriti shells are generated by the industrial extraction of buriti oil (Resende, Franca, & Oliveira, 2019). From this residue, the buriti shell, there is a lack of information related to its use and, to the best of our knowledge, only few studies are available in the literature. Pezoti Junior et al. (2014) evaluated the production of activated carbon while Resende et al. (2019) used buriti shells for flour production. França, Reber, Meireles, Machado, and Brunner (1999) described the supercritical CO₂ extraction from buriti pulp and shells, Tauchen et al. (2016) evaluated the Soxhlet extraction of different medicinal plants from the Peruvian Amazon, including the buriti shell, and Pereira-Freire et al. (2018) studied the chemopreventive action of buriti parts (pulp, shell and endocarp).

The “green extraction” concept emerged from low energy consumption processes, which allow the use of alternative solvents and natural renewable products, providing high quality and safe products (Vazquez-Roig & Picó, 2015).

* Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).

<https://doi.org/10.1016/j.foodchem.2019.125061>

Received 11 March 2019; Received in revised form 31 May 2019; Accepted 22 June 2019

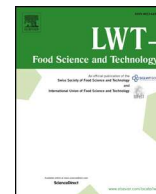
Available online 22 June 2019

0308-8146/ © 2019 Elsevier Ltd. All rights reserved.



Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Microencapsulation of ergosterol and *Agaricus bisporus* L. extracts by complex coacervation using whey protein and chitosan: Optimization study using response surface methodology

Adenilson Renato Rudke^{a,b,c}, Sandrina A. Heleno^{a,b}, Isabel P. Fernandes^{a,b}, M.A. Prieto^{a,d},
Odinei Hess Gonçalves^c, Alfrío E. Rodrigues^e, Isabel C.F.R. Ferreira^{a,**},
Maria Filomena Barreiro^{a,b,*}

^a Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253, Bragança, Portugal

^b Laboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials (LSRE-LCM), Polytechnic Institute of Bragança, Campus Santa Apolónia, 1134, 5301-857, Bragança, Portugal

^c Programa de Pós-Graduação em Tecnologia de Alimentos (PPGTA), Universidade Tecnológica Federal do Paraná, Campus Campo Mourão (UTFPR-CM), via Rosalina Maria dos Santos, 1233, CEP 87301-899, Caixa Postal: 271, Campo Mourão, PR, Brazil

^d Nutrition and Bromatology Group, Faculty of Food Science and Technology, University of Vigo, Ourense Campus, E32004, Ourense, Spain

^e Laboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials (LSRE-LCM), Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias s/n, 4200-465, Porto, Portugal

ARTICLE INFO

Keywords:

Microencapsulation
Whey protein/chitosan coacervates
Wastes valorization
Agaricus bisporus L.
Ergosterol
Response surface methodology

ABSTRACT

In the present work microencapsulation was applied to an ergosterol enriched extract (EEE) from *Agaricus bisporus* L. and pure ergosterol (PE) using a complex coacervation process. The process was optimized following two steps: (i) using response surface methodology to optimize the conditions of temperature (T , 55 to 95 °C), protein-to-chitosan ratio (P/C , 0.5 to 10.5), maximizing yield (Y_1 , %, w/w), efficiency (Y_2 , %, w/w) and load (Y_3 , %, w/w); and (ii) using the dose-response methodology to optimize the ergosterol content (E) at the optimal conditions achieved in (i). The global optimal conditions for both cases were the same (T of 55 °C and a P/C of 0.5), but with maximized responses of $Y_1 = 75.02\%$; $Y_2 = 100.00\%$, $Y_3 = 12.78\%$, and $Y_1 = 19.19\%$; $Y_2 = 100.00\%$, $Y_3 = 15.87\%$, respectively. The effect of increasing ergosterol content led to the reduction of the microencapsulation yield, but with an increase in the ergosterol load and maintenance of the microencapsulation efficiency.

1. Introduction

Agaricus bisporus L. is a mushroom extensively consumed worldwide in many different cultures (Rúbia Carvalho Gomes Corrêa, Brugnari, Bracht, Peralta, & Ferreira, 2016), representing a share of about 3.9 millions of tons of the global mushroom industrial production (“A detailed analysis of the recombination landscape of the button mushroom *Agaricus bisporus* var. *bisporus*,” n.d.). *A. bisporus* is cultivated in more than 70 countries, being appreciated for its sensory characteristics and health benefits (Liu, Jia, Kan, & Jin, 2013). It is a rich source of mycosterols, namely ergosterol (5,7,22-ergostatrien-3 β -ol), which represents about 90% of its sterol fraction (Barreira, Oliveira, & Ferreira, 2014). Ergosterol, and its peroxidation products are known as compounds of strong bioactivity exhibiting antioxidant, anti-inflammatory

and antitumor properties (Barreira & Ferreira, 2015). Ergosterol can act similarly to phytosterols in reducing cholesterol levels (Gil-ramírez, Ruiz-rodríguez, Marín, Reglero, & Soler-rivas, 2014), encouraging its use as a functional agent in the food industry (Heleno et al., 2017, pp. 103–110).

Although *Agaricus bisporus* L. presents a high concentration of ergosterol (Heleno et al., 2016), the low solubility of its free form, in both lipophilic and hydrophilic systems, limits its bioavailability (Rúbia C.G. Corrêa, Peralta, Bracht, & Ferreira, 2017). To circumvent these constraints, different techniques have been used to facilitate its use in different matrices.

The microencapsulation technique can be a solution to assure the protection of ergosterol against external agents and can also improve both the solubility and bioavailability of ergosterol. In this technique a

* Corresponding author. Centro de Investigação de Montanha (CIMO), Instituto Politécnico de Bragança, Campus de Santa Apolónia, 5300-253, Bragança, Portugal.

** Corresponding author.

E-mail addresses: iferreira@ipb.pt (I.C.F.R. Ferreira), barreiro@ipb.pt (M.F. Barreiro).

Cite this: *Food Funct.*, 2017, 8, 103

Development of dairy beverages functionalized with pure ergosterol and mycosterol extracts: an alternative to phytosterol-based beverages†

Sandrina A. Heleno,^{a,b} Adenilson R. Rudke,^{a,b} Ricardo C. Calhelha,^a Márcio Carochio,^{a,b} Lillian Barros,^{a,b} Odinei H. Gonçalves,^c Maria Filomena Barreiro^b and Isabel C. F. R. Ferreira^{*a}

In the present work, *Agaricus bisporus* extracts obtained by ultrasound-assisted extraction (UAE), and ergosterol, were incorporated into dairy beverages at concentrations mimicking commercial phytosterol-added yogurts, to work as alternatives. The samples were analysed for nutritional and bioactive properties, and compared with controls (yogurts with no additives or phytosterols), at two storage times (right after incorporation (ST = 0) and after seven days at 4 °C (ST = 7)). The ones incorporated with the extract (YAb) and with ergosterol at the same concentration as in the extract (YPEAb) showed similar antioxidant properties as the ones with phytosterols (YPhy), but a higher cytotoxicity against tumor cells. YPEPhy, the sample with ergosterol at the same amount as phytosterols in YPhy, was the strongest in both bioactivities. For YAb, YPEAb and YPEPhy the antioxidant capacity increased from ST = 0 to ST = 7, meaning that the extract and ergosterol protected the yogurt from oxidation, improving the shelf life. Nutritional parameters were identical for all samples.

Received 30th October 2016,
Accepted 12th December 2016

DOI: 10.1039/c6fo01600f

www.rsc.org/foodfunction

1. Introduction

The market for functional foods is evolving very fast, its growth estimated as being 10% per year. In this business segment, the fastest growing sector is the one of functional beverages (functional drinks)¹ which grew 2.5%, between 2008 and 2011, in Latin America.² Also in this context, functional dairy products in Germany had an impressive increment from 5 million dollars in 1995 to over \$300 million in 2000.³

Dairy beverages containing phytosterols, which are molecules claimed to be able to decrease cholesterol levels,⁴ can be currently found at the commercial level. In fact, the consumption of standardized levels of sterols is recommended by both European and US guidelines. Besides plants, these molecules also exist in macrofungi, in this case designated as mycosterols, ergosterol being the most abundant sterol in *Agaricus bisporus* (J. E. Lange) Imbach.^{5,6}

A. bisporus is the most cultivated and consumed mushroom worldwide, with an output of 4 million tons in 2009.⁷ This high production and consumption can be explained not only by its pleasant taste, but also by its biological properties, such as antioxidant,^{8,9} antimicrobial,^{8,10} anti-inflammatory,^{11,12} and antitumor¹³ properties among others. These bioactivities are related to bioactive molecules such as phenolic compounds and tocopherols,^{10,12} but also to ergosterol that represents approximately 90% of its sterol fraction.^{5,14,15} In addition, ergosterol is reported as having interesting hypocholesterolemic activity, acting like phytosterols.^{16,19}

The mushroom industry generates large quantities of by-products¹⁷ whose amount can vary between 20 and 35% in weight of fresh mushrooms.^{18,19} These residues can proceed from cultivation and harvest, where specimens with irregular dimensions and shape are discarded, but can also include other by-products such as the volva and bottom part of the stems due to their tough texture. They usually have no valued destination, being used for low-economic solutions such as animal feed and compost. Alternatively, these by-products can be proposed to extract ergosterol thus obtaining a high added value molecule for various industrial applications (100 g of the product with 98% of purity can cost about \$800).

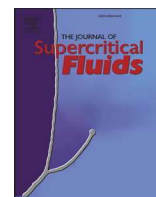
In the present work, mycosterol enriched extracts were prepared from *A. bisporus* bio residues by ultrasound-assisted extraction (UAE). These extracts, as well as pure ergosterol, were

^aMountain Research Centre (CIMO), ESA, Polytechnic Institute of Bragança, Portugal.
E-mail: iferreira@ipb.pt; Fax: +351273325405; Tel: +351273303219

^bLaboratory of Separation and Reaction Engineering – Laboratory of Catalysis and Materials (LSRE-LCM), Polytechnic Institute of Bragança, Portugal

^cPost-Graduation Program of Food Technology (PPGTA), Federal University of Technology – Paraná – UTFPR, Campus Campo Mourão, Brasil

†Electronic supplementary information (ESI) available. See DOI: 10.1039/c6fo01600f



High-purity κ -carrageenan from *Kappaphycus alvarezii* algae for aerogel production by supercritical CO₂ drying

Adenilson Renato Rudke^a, Cristiano José de Andrade^b, Sandra Regina Salvador Ferreira^{a,*}

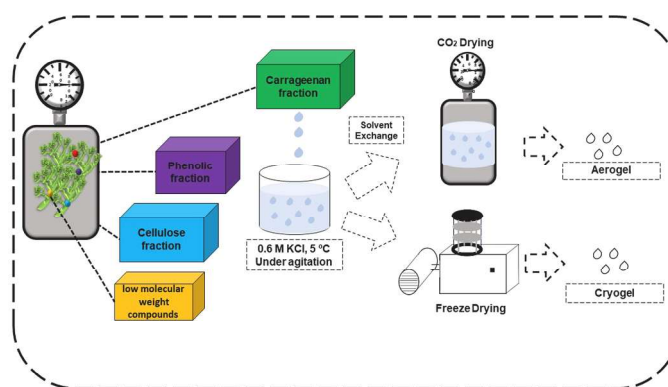
^a Chemical Engineering and Food Engineering Department, Graduate Program in Food Engineering (PPGEAL), Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900, Florianópolis, SC, Brazil

^b Chemical Engineering and Food Engineering Department, Graduate Program in Chemical Engineering (PósEng), Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900, Florianópolis, SC, Brazil

HIGHLIGHTS

- High purity *k*-carrageenan was used for aerogel production.
- Aerogel dried with scCO₂ showed high firmness compared to freeze dried cryogel.
- HP carrageenan provided aerogels with better water absorption than CC.
- Aerogel from HP carrageenan have larger surface area than obtained by CC.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:

Red seaweed
High-purity biopolymer
Cryogel, *k*-carrageenan
Commercial carrageenan

ABSTRACT

Carrageenan, a polysaccharide mostly extracted from *Kappaphycus alvarezii* (KA), is valuable for cosmetic and food uses due to large quantities of κ -carrageenan. High-pressure sequential extractions can recover high-purity carrageenan from KA, adequate for aerogel production. The biopolymer properties such as size, shape, and sulphate groups affect the gel form and aerogel characteristics. In this work, aerogels were obtained by supercritical CO₂ drying, and cryogels by freeze-drying, using high-purity carrageenan, recovered by sequential high-pressure extractions (HP), and commercial carrageenan (CC). The results indicated that HP samples showed higher volumetric shrinkage (96 %), firmness (254 N), and envelope density (0.008 g.cm⁻³) compared to CC samples. Aerogels presented characteristics of pore volume, surface area, and density suggesting supercritical drying as feasible method to produce porous materials. Besides, the aerogels present valuable properties compared to cryogel, including high firmness, useful for applications in packages, scaffolds, or delivery systems, a tendency that must be increasingly explored.

* Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).

<https://doi.org/10.1016/j.supflu.2024.106454>

Received 26 June 2024; Received in revised form 7 November 2024; Accepted 7 November 2024

Available online 12 November 2024

0896-8446/© 2024 Published by Elsevier B.V.



Phenolic Compounds and Pectin-Rich Extracts Recovered from Peach Pomace by Sequential Pressurized Liquid Extractions

Carla Roana Monteiro Rudke¹ · Adenilson Renato Rudke¹ · Amanda Tavares Germano² · Luciano Vitali² · Acácio Antônio Ferreira Zielinski¹ · Sandra Regina Salvador Ferreira¹

Received: 24 June 2024 / Accepted: 17 December 2024

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2025

Abstract

Phenolics and pectin compounds were fractionated from peach pomace by sequential pressurized liquid extraction (PLE) with ethanol and citric acid solution, and the results were compared with low-pressure methods of Soxhlet and heat stirring extraction (HSE). PLE provided higher phenolic content, low reducing sugar, and the best antioxidant potential by DPPH, ABTS, and FRAP methods. The main recovered phenolics were protocatechuic acid, mandelic acid, and vanillin, which are valuable for cosmetic, food, and pharmaceutical products. The pectin yield was 14% for PLE and 20% for HSE, with galacturonic acid content of 47% and 10.9%, respectively, suggesting application in low-calorie products. The pectin fractions showed good emulsification and foaming ability and stability, with the PLE samples presenting higher water solubility and oil-holding capacity, and lower water-holding capacity compared to the HSE sample. These results endorse peach pomace as a relevant biomass for the recovery and fractionation of bioactive compounds by innovative methods. The novel technological properties evaluated for the pectin fraction indicate promising attributes for applications in food formulations.

Keywords Pressurized liquid extraction · Functional properties · Emergent technique · Co-product

Highlights

- Sequential PLE showed promising behavior for fractionating phenolics and pectin from peach pomace.
- The main phenolics recovered from peach pomace were protocatechuic acid, mandelic acid, and vanillin.
- PLE achieved a similar pectin yield with a higher content of galacturonic acid, compared to the HSE method.
- Novel functional properties of pectin from peach pomace were evaluated.
- Good foaming and emulsion ability from PLE pectin extract.

✉ Sandra Regina Salvador Ferreira
s.ferreira@ufsc.br

Carla Roana Monteiro Rudke
carla.roana@posgrad.ufsc.br

Adenilson Renato Rudke
adenilsonrudke@gmail.com

Amanda Tavares Germano
amanda.tavares@ufsc.br

Luciano Vitali
luciano.vitali@ufsc.br

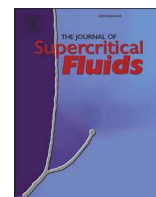
Introduction

Peach fruit is globally recognized as a specialty crop and the sixth most important fruit in the world market (Anthony and Minas, 2022). The co-product of peach juice processing is the pomace, composed of the fruit peel and pulp, representing a significant amount of underutilized agro-industrial biomass (Rudke et al., 2024). According to Faostat (2022), Brazilian peach and nectarine production reached 208,823 tons in 2022, while world production exceeded 24.5 million tons. Peach pomace represents approximately 10% of the initial fruit weight,

Acácio Antônio Ferreira Zielinski
acacio.zielinski@ufsc.br

¹ Chemical Engineering and Food Engineering Department, Federal University of Santa Catarina, Box 476, Florianópolis, SC 88040-970, Brazil

² Department of Chemistry, Federal University of Santa Catarina, Florianópolis, SC, Brazil



Sequential high-pressure extraction using green solvents to recover bioactive compounds from sesame cake

Marta Alessandra de Avila Souza^a, Adenilson Renato Rudke^a, Amanda Tavares Germano^b, Luciano Vitalli^b, Sandra Regina Salvador Ferreira^{a,*}

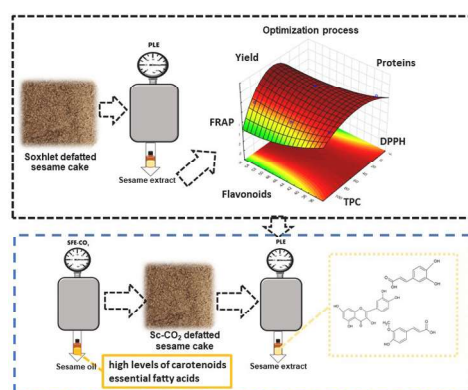
^a Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA/UFSC, C.P. 476, Florianópolis, SC CEP 88040-900, Brazil

^b Chemistry Department – Federal University of Santa Catarina, Brazil

HIGHLIGHTS

- Sequential extractions from sesame cake recover highly functional phenols.
- PLE with ethanol provided samples with high DPPH and FRAP values.
- SFE recovers compounds with antioxidant and nutritional values.
- Sequential SFE and PLE methods were effective for biocomponents recovery.
- Sesame cake is a good source of valuable components.

GRAPHICAL ABSTRACT



ARTICLE INFO

Keywords:

Defatted sesame cake
Supercritical CO₂
Pressurized liquid extraction
Phenolic compounds
Antioxidant activity

ABSTRACT

Sesame cake was submitted to pressurized liquid extraction (PLE) for process optimization. Then, supercritical fluid extraction (SFE), followed by optimized PLE were applied to recover the oily fraction and the polar extract, respectively. PLE samples, at optimized condition and from SFE defatted cake, showed high levels of TPC (33.15 and 31.86 mg GAE/g), DPPH (97.64 and 94.38 μmol TE/g), FRAP (46.12 and 46.69 mg TE/g), flavonoids (2.26 and 2.31 mg QE/g extract), yield (13.76 and 16.25 %) and protein (56.52 and 54.08 mg BSA/g), respectively. The oily fraction presented high levels of carotenoids and essential fatty acids, while PLE extracts presented higher concentration of ferulic acid, 4-aminobenzoic acid, and quercetin compared to Soxhlet extract. Total Reduced Sugar (TRS) content suggests sesame cake as good biomass for bioethanol production. The sequential process (SFE + PLE) was efficient to recover two bioactive fractions from sesame cake, contributing to improve the value of this co-product.

* Corresponding author.

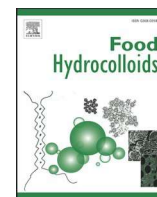
E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).

<https://doi.org/10.1016/j.supflu.2024.106421>

Received 8 August 2024; Received in revised form 25 September 2024; Accepted 28 September 2024

Available online 30 September 2024

0896-8446/© 2024 Published by Elsevier B.V.



Deconstruction of *Kappaphycus alvarezii* biomass by pressurized solvents to increase the carrageenan purity

Adenilson Renato Rudke^a, Eduardo Zanella^b, Boris U. Stambuk^b, Cristiano José de Andrade^a, Sandra Regina Salvador Ferreira^{a,*}

^a Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900, Florianópolis, SC, Brazil

^b Yeast Molecular Biology and Biotechnology Laboratory, Department of Biochemistry, Federal University of Santa Catarina, Florianópolis, SC, Brazil

ARTICLE INFO

Keywords:

Red seaweed
Biopolymer
Green extraction
Biorefinery

ABSTRACT

Kappaphycus alvarezii (KA) is a natural renewable resource of valuable products with a high concentration in κ -carrageenan and other bioactive components that can be recovered applying the biorefinery approach. This study aimed to sequentially extract components from KA biomass, including phenolic compounds, carrageenan, low molecular weight compounds, and cellulose, using high-pressure methods. The first step on the KA deconstruction is to recovery of phenolics with ethanol using Soxhlet and Pressurized Liquid Extraction (PLE) methods. KOH was applied for the KA biomass pretreatment. Sequentially, the carrageenan fraction was extracted by low- and high-pressure methods, and the recovered carrageenan samples were characterized by Fourier transform infrared spectroscopy (FTIR), viscosity, gel strength, Gel Permeation Chromatography (GPC), and chemical composition. Scanning electron microscope (SEM) analysis detected the KOH influence and the separation of carrageenan and cellulose materials. Although both extraction routes (low- and high-pressure methods) presented similar recovery yields in phenolics, carrageenan, and cellulosic fractions, the high-pressure route was more efficient in terms of processing time, solvent, and energy consumption. Besides, the novelty of this study was the use of high-pressure sequential procedures for the fractionation of KA, highlighting the effect of the process on the carrageenan characteristics.

1. Introduction

Red algae are remarkable sources of biopolymers such as carrageenan, a hydrocolloid that can be used in different food formulations such as jam, marshmallow, ice-cream, pudding, cooked ham, hamburger, cake glaze, salad dressings, among others (Geada et al., 2021; Naseri et al., 2019; Roldán et al., 2017; Simatupang et al., 2021). Carrageenan is commercialized around 5.50 to 9.00 dollars per kg, depending on its purity: semi-refined or refined (Kumar et al., 2020), respectively. Within seaweeds, *Kappaphycus alvarezii* (KA) stands out for its fast growth (100–120 days) and high content of κ -carrageenan, one of the basic carrageenan forms (μ , ν , κ and ι) with adequate properties for food, pharmaceutical, and cosmetic products, acting as gelling, thickening, and stabilizing agent (Ali et al., 2020; Kumar et al., 2020; Rupert et al., 2022).

In addition to carrageenan, KA contains fatty acids, pigments, phenolic compounds, proteins, and cellulose that can be recovered

through sequential extractions (Rudke et al., 2020). The sequential extraction approach can lead to different fractions – aligned with the biorefinery concept (Torres, Kraan, & Domínguez, 2019), providing different products and maximizing the biomass value (Ingle et al., 2018). However, the main challenges associated with algae biorefinery are the development and control of the extraction processes, ensuring high yields while maintaining the quality of the recovered fractions. Therefore, considering the high number of process variables involved, it is essential to develop a careful and well-detailed sequential extraction applied to algae biomass, in particular KA. To the best of our knowledge, it has been little investigated.

The sequential extraction of KA was conducted to obtain a polar fraction (extract) with antioxidant activity and the carrageenan fraction, focusing on maximizing the antioxidant extractions without affecting the physical properties of the carrageenan. The design of sequential approach used was based on Gilbert-López et al. (2017), Gilbert-López et al. (2015), and Rebelatto et al. (2020), i.e., the sequential processes

* Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).

<https://doi.org/10.1016/j.foodhyd.2024.110204>

Received 22 January 2024; Received in revised form 9 May 2024; Accepted 14 May 2024

Available online 15 May 2024

0268-005X/© 2024 Published by Elsevier Ltd.



Trends in Dairy Products: New Ingredients and Ultrasound-Based Processing

Carla Roana Monteiro Rudke¹ · Callebe Camelo-Silva¹ · Adenilson Renato Rudke¹ · Elane Schwinden Prudencio^{1,2} · Cristiano José de Andrade¹

Received: 23 February 2023 / Accepted: 21 June 2023

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2023

Abstract

Demanding consumers increasingly seek products with a more nutritional appeal that contribute to nutritional health. Considering the requirements of sustainable processes, natural ingredients, and healthier products, this review describes the most recent trends in dairy products, focusing on new ingredients and ultrasound technology. These ingredients include prebiotics, probiotics, and synbiotics; substitutes for reducing sugar and lipids; and natural preservatives such as nisin. Also, ultrasounds have been identified as a promising strategy for processing food products since it can increase shelf-life and enhance sensorial acceptance.

Keywords Postbiotics · Whey protein · Emerging technology · Bacteriocin

Introduction

The demand for appealing foods that contribute to well-being and health has encouraged the development of new products and new technologies. In this context, the dairy industry constantly develops and implements innovations, mainly correlated to new ingredients and emerging technologies instead of those used traditionally. Milk and milk-based products are among the most consumed foods in various meals in different countries. For this reason, they are a suitable option for

delivering new ingredients and being subjected to new technologies. Fortifying dairy products with new ingredients is a strategy accepted by scientists, food manufacturers, and consumers. Utilizing new components and developing novel dairy products create significant value for the food industry while improving the nutritional characteristics of the product. Granato et al. (2022) highlighted that, considering rising consumer demands and expectations for more nutritious dairy foods, food companies of differing sizes have invested in developing dairy foods with added ingredients that may boost consumer health, the so-called functional foods (Rudke et al., 2022).

Dairy products with nutritional and health claims, i.e., food products that have beneficial nutritional properties due to nutrients or other added substances, such as probiotics, prebiotics, synbiotics, and postbiotics, with reduced sugar, low fat, and whey protein, play an essential role in the current scenario of dairy processors. The dairy industry has new perspectives in developing novel and innovative products with added functional properties driven by the consumer demand for healthier food products. In addition to health, consumers are concerned about safe food, which is nourishing while being free from pathogenic microorganisms. Therefore, additives and new technology that restrict and eliminate pathogens are important. Among the additives, nisin is a bacteriocin (against Gram positive) that acts as a natural preservative, especially in dairy products, being the only natural antimicrobial peptide approved by the US Food and Drug Administration (FDA) for this. According

Callebe Camelo-Silva and Carla Roana Monteiro Rudke contributed equally.

✉ Cristiano José de Andrade
cristiano.andrade@ufsc.br

Carla Roana Monteiro Rudke
carla.roana@posgrad.ufsc.br

Callebe Camelo-Silva
callebecamelosilva@gmail.com

Adenilson Renato Rudke
adenilsonrudke@gmail.com

Elane Schwinden Prudencio
elane.prudencio@ufsc.br

¹ Postgraduate Program in Food Engineering, Technology Center, Federal University of Santa Catarina, TrindadeFlorianópolis, SC 88040-970, Brazil

² Department of Food Science and Technology, Agricultural Sciences Center, Federal University of Santa Catarina, ItacorubiFlorianópolis, SC 88034-001, Brazil



Contents lists available at ScienceDirect

Algal Research

journal homepage: www.elsevier.com/locate/algal

Green extraction of phenolic compounds and carrageenan from the red alga *Kappaphycus alvarezii*

Adenilson Renato Rudke^a, Mayara da Silva^b, Cristiano José de Andrade^a, Luciano Vitali^b, Sandra Regina Salvador Ferreira^{a,*}

^a Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900 Florianópolis, SC, Brazil

^b Department of Chemistry, Federal University of Santa Catarina, Florianópolis, SC, Brazil

ARTICLE INFO

Keywords:

Red seaweed

Circular economy

Non-conventional extraction methods

Biopolymer

ABSTRACT

Kappaphycus alvarezii (KA) is a widespread worldwide alga, and one of the main industrial sources of carrageenan. Besides, KA biomass also contains other substances such as phenolic compounds and fatty acids that can be recovered by several methods. Then, this work aimed to investigate the eco-friendly methods, for the recovery of fatty acids, phenolics, and carrageenan fractions. The eco-friendly methods are faster, produce higher yields, and can be cost-effective in comparison with conventional methods. The performance of the eco-friendly methods (supercritical fluid, pressurized liquid, microwave assisted, and high-pressure carrageenan extractions) was compared with conventional techniques (maceration or Soxhlet) in terms of yield, chemical profile by gas and liquid chromatography, total phenolic content (TPC), antioxidant activity by 1,1-diphenyl-2-picrylhydrazyl (DPPH) and Ferric reducing antioxidant power (FRAP) procedures, viscosity and gel strength of the carrageenan fraction. The results showed pressurized liquid extraction samples with the highest antioxidant potential and TPC (up to 2 to 4 times higher than conventional). Besides, the carrageenan fraction was efficiently recovered by microwave assisted extraction (MAE) and by pressurized-water carrageenan extraction (PWCE), and the samples presented viscosity and gel strength similar to that obtained by water maceration.

1. Introduction

Kappaphycus alvarezii (KA), also known as *Eucheuma cottonii* (Rhodophyta), is the 5th most cultivated macroalgae worldwide, mainly due to its rapid growth rate (about 4.5 % daily) and its high carrageenan content, a polysaccharide from the algae cell walls, which is widely used in food (cheese, puddings, dairy desserts, hamburgers, and sausages, among others), pharmaceuticals (mainly as excipients for controlled release), and cosmetics industries (toothpaste, skin lotions, and shaving foams) [1].

Carrageenan constitutes the largest mass fraction of KA (39 %) [2]. In addition, the seaweed also contains pigments [3], phenolic compounds [3], proteins [4], minerals, fatty acids [4], and other carbohydrates (cellulose and some monosaccharides) [1], which can be extracted by different methods. In general, conventional extraction techniques are time- and solvent-consuming, while alternative eco-friendly techniques such as subcritical water extraction (SWE), pressurized liquid extraction (PLE), ultrasound assisted extraction (UAE), microwave-assisted

extraction (MAE), supercritical fluid extraction (SFE), among others, usually lead to good performance and high productivity.

The literature presents data regarding the antioxidant activity of KA biomass [5–7] nevertheless most of them are related to the antioxidant activity from aqueous extracts, which also solubilize proteins and carrageenan, along with the phenolic components. Besides, other reports discuss about extracts from KA obtained using solvents such as acetone, ethanol, methanol, hexane, ethyl acetate, which are more selective than water and aqueous solutions, and present low carrageenan solubility [8,9]. For instance, Uy et al. [10] used MAE with aqueous solutions of different solvents (methanol, ethanol, acetone or 2-propanol) for the recovery of carrageenan. Baskararaj et al. [3] optimized the MAE conditions to obtain a phenolic-rich sample from KA using methanolic aqueous solution (57.5 to 87.5 %). Gereniu et al. [7], using PLE, evaluated the hydrolysate obtained from KA using water, 1 % formic acid, and 1 % sodium hydroxide. Gereniu et al. [11] considered subcritical water modified with ionic liquids for carrageenan extraction from KA. Therefore, unprecedentedly, the aim of this work was to

* Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).



Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

A comparative study of phenolic compounds profile and *in vitro* antioxidant activity from buriti (*Mauritia flexuosa*) by-products extracts

Adenilson Renato Rudke^a, Kátia Suzana Andrade^a, Simone Mazzutti^a, Acácio Antônio Ferreira Zielinski^a, Victor Rodrigues Alves^b, Luciano Vitali^b, Sandra Regina Salvador Ferreira^{a,*}

^a Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900, Florianópolis, SC, Brazil

^b Department of Chemistry, Federal University of Santa Catarina, Florianópolis, SC, Brazil

ARTICLE INFO

Keywords:

Green extraction methods
Residue valorization
Multivariate analysis
Aguaje

ABSTRACT

In general, buriti seeds (BSE) and buriti shells (BSH) are discarded or used as animal feed. However, these materials may have other destinations. Therefore, the aim of this work was to obtain extracts from BSE and BSH using different extraction techniques and solvents in order to evaluate their effects on phenolic profile and antioxidant capacity of the recovered extracts. Global yield, total phenolic content (TPC), *in vitro* antioxidant activities, and phenolic composition accessed by LC-ESI-MS/MS were evaluated. Principal component analysis (PCA) was used as a tool to correlate the observed data. Raw material, solvent type, and extraction method influenced the obtained results mainly in relation to the phenolic composition. BSH showed higher values of global yield, antioxidant activity, and TPC, compared to BSE. Considering the 46 phenolic compounds analyzed, 28 were quantified from BSE and 33 from BSH samples. Protocatechuic acid was the major phenolic compound found in most samples, except for the BSH extract obtained with pressurized liquid extraction (PLE), which presented quercetin as the main phenolic compound. PCA analysis demonstrated that flavonoids are most associated with the BSH, while phenolic acids and phenolic aldehydes are most related to BSE samples.

1. Introduction

The buriti (*Mauritia flexuosa* L.) is a palm tree that produces fruits of the same name, which pulp is used by the food industry to produce sweets, ice cream, juices, jams, and oil (Resende, Franca, & Oliveira, 2019). The oil extracted from buriti pulp can be used in cosmetic industries due to its emollient and sunscreen properties, useful for preparation of lotions, creams, soaps, shampoos, and more elaborate products (Fuentes et al., 2013; Koolen, Silva, Silva, Paz, & Bataglion, 2018). These industrial applications are associated with buriti pulp, which corresponds to only 18–30% of the fruit (Barbosa, Lima, & Mourão Junior, 2010). The remaining parts: shell, endocarp, and seed are usually discarded, or used for handicrafts production or animal feed (Sampaio & Carrazza, 2012). Besides, the buriti palm tree presents high importance for extractive activity at the North and Northeast regions of Brazil and, even considering the limited information related to this crop, it is estimated that buriti residues (shell, endocarp, and seed) reach about 18 tons per hectare cultivated each year (Cymerys, Fernandes, &

Rigamonte-Azevedo, 2005).

Research about buriti seeds (BSE) and buriti shells (BSH) are scarce in the literature. For instance, some studies reported the use of BSE for the synthesis of activated carbon (Beltrán-Suito et al., 2015), to detect phytosterol and tocopherols content (Costa, Ballus, Teixeira-Filho, & Godoy, 2010), the lipidic profile of the oily fraction (Costa, Ballus, Filho, & Godoy, 2011), and the phenolic content and antioxidant capacity (Contreras-Calderón, Calderón-Jaimes, Guerra-Hernández, & García-Villanova, 2011). Besides, researches about BSH are generally related to their use as supplement to animal feed (Ferreira et al., 2017), for activated carbon production (Pezoti Junior et al., 2014), flour production (Resende et al., 2019) composition and chemical stability of the BSH oil (Forero-Doria et al., 2016), phenolic composition and antioxidant activity (Rudke, Mazzutti, Andrade, Vitali, & Ferreira, 2019; Tauchen et al., 2016), antiplatelet and antithrombotic activity (Fuentes et al., 2013), and chemopreventive action (Pereira-Freire et al., 2018). This scarcity of research demonstrates the scientific potential contribution of the present study, contributing to value a biomass, mostly treated as

* Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).



Contents lists available at ScienceDirect

Trends in Food Science & Technology

journal homepage: www.elsevier.com/locate/tifs

Kappaphycus alvarezii macroalgae: An unexplored and valuable biomass for green biorefinery conversion

Adenilson Renato Rudke, Cristiano José de Andrade, Sandra Regina Salvador Ferreira^{*}

Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA/UFSC, C.P. 476, CEP 88040-900, Florianópolis, SC, Brazil

ARTICLE INFO

Keywords:

Red seaweed
Bioactive molecules
Circular economy
Eco-friendly extraction methods
Algae carbohydrates

ABSTRACT

Background: *Kappaphycus alvarezii* is the 5th world's most cultivated macroalgae, since it is an essential source of carrageenan, widely used in food industry. However, *K. alvarezii* is an unexplored biomass for green biorefinery conversion, since its composition includes valuable proteins, lipids, phenolic compounds, among others. Although there are reviews on *K. Alvarezii* cultivation and pharmacological properties, no information is available regarding extraction techniques applied to this algae biomass. Therefore, this review covers the lack of information on biorefinery concept applied to *K. alvarezii* and suggest sequential extractions to recover carrageenan and high-added value molecules by using non-conventional methods.

Scope and approach: This critical review presents the most recent data on *K. alvarezii*, including its scientific trends, production and potential. It also deals with non-traditional methods for sequential extractions applied to *K. alvarezii*. The search for available data was extended to the group of red algae to consider the concept of biorefinery.

Key findings and conclusions: *K. alvarezii* biomass can be used to obtain chlorophyll, β -carotene, essential amino acids (aspartic acid, glutamic acid and phenylalanine) and phytohormones (indole acetic acid, zeatin, kinetin and gibberellic acid). Therefore, we provide several sustainable insights to sequentially recovery carrageenan and other bioactive compounds from *K. alvarezii*.

1. Introduction

The oceans are remarkable sources of unexplored and valuable materials, in particular seaweed, since they contain very unique molecules including phenols, pigments, polysaccharides, proteins and bioactive peptides, among others (Pangestuti, Getachew, Siahaan, & Chun, 2019; Pangestuti, Siahaan, & Kim, 2018). Furthermore, it is worth mention that the seaweed cultivation is well aligned with the principles of sustainable production, since seaweed can mitigate around 20 tons of CO₂/hectare/year, there is no need of fresh water, and no competition for land, in relation to food production (Hargreaves, Barcelos, da Costa, & Pereira, 2013).

Based on the photosynthetic pigments, seaweeds can be classified into three groups: green algae (Chlorophyta), brown algae (Phaeophyta) and red algae (Rhodophyta). Among them, red algae comprise more than 60% out of 30 thousand tons of algae cultivated around the world (FAO, 2018a). The main interest on red algae is related to their easy cultivation and high content of unique polysaccharides (40–50% of the dry weight), in particular carrageenan and agar (FAO, 2018b;

Khambhaty et al., 2012; Solorzano-Chavez et al., 2019; Torres, Flórez-Fernández, & Domínguez, 2019). In this sense, red seaweed species, *Kappaphycus alvarezii* (KA), *Eucheuma denticulatum*, *Chondrus crispus*, and *Sarcothalia crispata*, are the main sources of carrageenan, at industrial scale (Naseri, Holdt, & Jacobsen, 2019).

Besides, seaweed in general present several high-added value molecules such as minerals, polyphenols, lipids and proteins (peptides) which are mostly scientifically and industrially unexplored.

According to the green chemistry principles, the recovery of high added-value molecules by using environmental friendly extraction methods should be inherently associated to the concept of biorefinery, which aims to obtain, as extended as possible, a wide variety of products and energy (Cherubini, 2010; Herrero & Ibañez, 2018). In this context, green non-conventional extraction methods such as pressurized liquid extraction (PLE), subcritical water extraction (SWE), supercritical fluid extraction (SFE), microwave-assisted extraction (MAE), and ultrasound-assisted extraction (UAE) have been only recently associated to biorefinery concept by the scientific community.

Although there are some scientific reports about red algae

^{*} Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).



Sequential green-based extraction processes applied to recover antioxidant extracts from pink pepper fruits

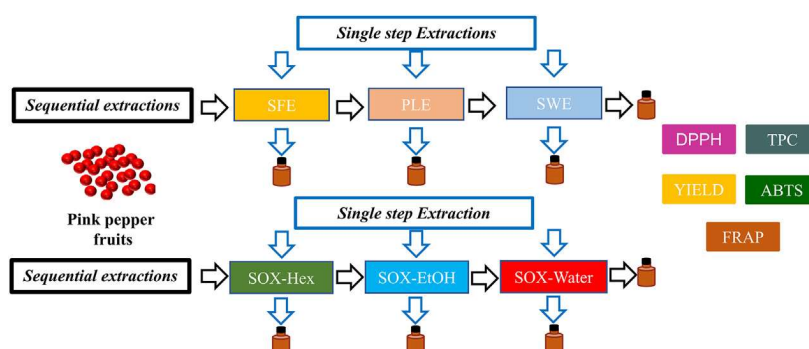
Evertan A. Rebelatto, Luiz Gustavo G. Rodrigues, Adenilson R. Rudke, Kátia S. Andrade, Sandra R.S. Ferreira*

Chemical and Food Engineering Department – Federal University of Santa Catarina – EQA/UFSC, CEP 88040-900, Florianópolis, SC, Brazil

HIGHLIGHTS

- Integrated high-pressure processes were applied to recovery compounds from pink pepper.
- First study on obtaining sequential SOX extractions of pink pepper fruits.
- A defatting step of the raw material by SFE improve the quality of the extracts.
- Integrated operations were successfully applied in the recovery of extracts rich in bioactive compounds from pink pepper.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:

Received 9 July 2020

Received in revised form 18 August 2020

Accepted 24 August 2020

Keywords:

Schinus terebinthifolius
bio-refinery
high-pressure extraction
phenolic compounds

ABSTRACT

Integrated high-pressure processes, combining Supercritical CO₂ extraction (SFE-CO₂), Pressurized Liquid Extraction (PLE), and Subcritical Water Extraction (SWE), were used to obtain antioxidant compounds from pink pepper fruits. The recovered extracts were characterized in terms of total phenolic content (TPC) and antioxidant activity, by the methods DPPH (1,1-diphenyl-2-picrylhydrazyl method), ABTS (2,2'-Azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) and FRAP (Ferric reducing antioxidant power). The processes combination proved to be efficient for the recovery of extracts with high antioxidant potential. The best extraction route was the one that combined SFE at 30 MPa and 333 K, followed by PLE with ethanol at 10 MPa and 353 K and SWE at 10 MPa and 403 K. PLE and SWE assisted by SFE showed to be efficient and green alternatives for the recovery of antioxidants compounds.

© 2020 Elsevier B.V. All rights reserved.

1. Introduction

Schinus terebinthifolius Raddi, *Anacardiaceae* family, is a Brazilian native plant, also known as Aroeira or Brazilian peppertree. The dried fruits of this plant are widely used in cooking as an appreciated and exotic seasoning, well known as pink pepper. Aroeira fruits

has been used to replace black pepper and, according to chemical analyzes reported in the literature, there is great similarity between its chemical components. Besides, all parts of *S. terebinthifolius* are used in traditional medicine for the treatment of various pathologies [1–4]. In traditional medicine, pink pepper has been used as a remedy for ulcers, respiratory problems, wounds, rheumatism, gout, diarrhea, skin ailments, and arthritis, as well as to treat tumors and leprosy [5].

The extraction techniques and solvents used for the recovery of valuable compounds from natural products or biomass must be

* Corresponding author.

E-mail address: s.ferreira@ufsc.br (S.R.S. Ferreira).



The Open Food Science Journal

Content list available at: <https://openfoodsciencejournal.com>



RESEARCH ARTICLE

Evaluation of the Antimicrobial Activity of Buriti (*Mauritia Flexuosa*) Pulp Extracts

Carla Roana Moraes Monteiro^{1,*}, Adriele Rodrigues dos Santos¹, Marcos Vieira da Silva², Adenilson Renato Rudke³, Iara de Melo Rodrigues¹, Eliane Sloboda Rigobello¹ and Márcia Regina Ferreira Geraldo Perdoncini¹

¹Department of Food Engineering, Campo Mourão Campus (UTFPR-CM), Federal Technological University of Paraná, via Rosalina Maria dos Santos, 1233, CEP 87301-899, Campo Mourão-PR, Brazil

²Farroupilha Federal Education, Science and Technology Institute, Alegrete, Rio Grande do Sul, Brazil

³Laboratory of Thermodynamic and Supercritical Technologies (LATESC), Chemical and Food Engineering Department, Federal University of Santa Catarina, EQA-UFSC, CEP 88040-900, Florianópolis-SC, Brazil

Abstract:

Background:

Buriti (*Mauritia flexuosa*) is a palm tree typical of the Amazon region. This plant belongs to the *Arecaceae* family and is economically important because it contains substances important for the food, cosmetic and pharmaceutical industries. It has, in its fruits, compounds with antimicrobial potential.

Objective:

The objective of this study was to evaluate the minimal inhibitory concentration and minimum bactericidal concentration of the Buriti extracts against the four bacteria: *Salmonella enterica* serotype Typhimurium ATCC 14028, *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922 and *Pseudomonas aeruginosa* ATCC 27853.

Methods:

15 extracts from buriti pulp were obtained varying in temperature, mass of buriti and ethanol content. The antimicrobial activity of these extracts was evaluated. To determine the minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC), the methodology recommended by the Clinical and Laboratory Standards Institute was followed.

Results:

The results showed which buriti pulp extracts had strong inhibitory activity. Gram-positive results ranged from 21 to 78 $\mu\text{g.mL}^{-1}$. For Gram-negative, they ranged from 30 to 111 $\mu\text{g.mL}^{-1}$.

Conclusion:

The buriti extracts significantly slowed the growth of the tested bacteria.

Keywords: Buriti, Antimicrobial activity, Pulp extract, Minimum Inhibitory Concentration, Minimum Bactericidal Concentration, *Mauritia Flexuosa*.

Article History

Received: August 15, 2019

Revised: October 16, 2019

Accepted: November 07, 2019

1. INTRODUCTION

Food is required to meet the increasing demands in our daily life. Reproduction of microorganisms is the most important

factor in the spoilage of perishable foods [1]. There is concern over groups of microorganisms responsible for food spoilage, leading to unpleasant smells, flavors and colors that decrease shelf life [2]. In addition, food borne outbreaks could cause serious economic losses [3]. So, preservatives that can maintain the quality of these foods for a longer time should be used. However, the industry still uses chemical preservatives that no

* Address correspondence to this author at the Department of Food Engineering, Campo Mourão Campus (UTFPR-CM), Federal Technological University of Paraná, via Rosalina Maria dos Santos, 1233, CEP 87301-899, Campo Mourão-PR, Brazil; Tel: +554435181400; E-mail: roanamoraes@hotmail.com;