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**DE ALIMENTOS**

NARA RÚBIA RODRIGUES DO NASCIMENTO SILVA

**Bioacessibilidade de carotenoides de buriti, jambolão e jabuticaba**

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UNIVERSIDADE FEDERAL DE GOIÁS  
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NARA RÚBIA RODRIGUES DO NASCIMENTO SILVA

**Bioacessibilidade de carotenoides de buriti, jambolão e jabuticaba**

Tese apresentada ao Programa de Pós-Graduação em Ciência e Tecnologia de Alimentos (PPGCTA), em 11 de maio de 2022, na Escola de Agronomia da Universidade Federal de Goiás (UFG), como exigência para a obtenção do título de doutora em Ciência e Tecnologia de Alimentos.

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**Orientador:** Prof. Dr. Flávio Alves da Silva

**Coorientador:** Prof. Dr. Rodrigo Barbosa Monteiro Cavalcante

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## ATA DE DEFESA DE TESE

Ata Nº 61 da sessão de Defesa de Tese de Nara Rúbia Rodrigues do Nascimento Silva que confere o título de Doutora em Ciência e Tecnologia de Alimentos, na área de concentração em Ciência e Tecnologia de Alimentos.

Aos onze dias do mês de maio de dois mil e vinte e dois, a partir das treze hora e trinta minutos, por videoconferência, realizou-se a sessão pública de Defesa de Tese intitulada “BIOACESSIBILIDADE DE CAROTENOÍDES DE BURITI, JAMBOLÃO E JABOTICABA”. Os trabalhos foram instalados pelo Orientador, Professor Flávio Alves da Silva (EA/UFG), com a participação dos demais membros da Banca Examinadora: Professor Julião Pereira (EA/UFG), membro titular interno; Doutora Gardênia Martins de Sousa (PósDoc/EA/UFG), membro titular externo; Professor Menandes Alves de Souza Neto (UNIFAN), membro titular externo; e Professora Daniele Bobrowski Rodrigues (UNB), membro titular externo; além do coorientador Professor Rodrigo Barbosa Monteiro Cavalcante (FANUT/UFG). Durante a arguição os membros da banca não fizeram sugestão de alteração do título do trabalho. A Banca Examinadora reuniu-se em sessão secreta a fim de concluir o julgamento da Tese tendo sido a candidata aprovada pelos seus membros. Proclamados os resultados pelo Professor Flávio Alves da Silva, Presidente da Banca Examinadora, foram encerrados os trabalhos e, para constar, lavrou-se a presente ata que é assinada pelos Membros da Banca Examinadora, aos onze dias do mês de maio de dois mil e vinte e dois.

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## **DEDICATÓRIA**

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*“Tudo parece impossível até que seja feito”*  
(Nelson Mandela)

## **Resumo**

A determinação da fração bioacessível fornece informações valiosas a respeito da dosagem recomendada de cada composto correspondente em sua fonte alimentar, de maneira a garantir a adequada eficácia nutricional. Assim, este trabalho objetivou ser pioneiro no estudo de bioacessibilidade de carotenoides de polpa de *M. flexuosa* e *S. cumini*, e em fruto inteiro de *P. jaboticaba*. A digestão foi dividida em três fases: oral, gástrica e intestinal, nas quais se controlou temperatura, pH, tempo e agitação, além de simular as condições enzimáticas a que o alimento está exposto. A solução final (quimo) foi separada para extração de carotenoides ou passou por centrifugação, sendo separada a fração micelar, que também foi utilizada para extração de carotenoides, que foram extraídos com metanol. Observou-se que o processo de digestão *in vitro* evidenciou redução significativa nos teores totais de carotenoides para todos os frutos. Originalmente, foram identificados em polpa de *M. flexuosa* os seguintes compostos: todo-*trans*-fitoeno, todo-*trans*-fitofluen, *cis*-β-caroteno, todo-*trans*-β-caroteno e todo-*trans*-β-carotene; somando um total de 143,49 µg.g<sup>-1</sup>. No quimo foram identificados todo-*trans*-luteína, todo-*trans*-fitoeno, *cis*-fitoflueno, *cis*-α-cryptoxantina, todo-*trans*-α-cryptoxantina e todo-*trans*-β-cryptoxantina; totalizando 7,26 µg.g<sup>-1</sup>. Por fim, na fração micelar foi possível apenas a identificação de 5,8-epoxy-β-cryptoxantina, em concentração de 0,11 µg.g<sup>-1</sup>, assim apenas 0,077% do total de carotenoides ficam bioacessíveis após a digestão simulada. A fração bioacessível de carotenoides em polpa de *S. cumini* é 9,30%, sendo que se observa um aumento de todo-*trans*-β-caroteno (bioacessibilidade = 133,33%), e redução de 15-*cis*-β-caroteno (bioacessibilidade = 20%) e fitoeno (bioacessibilidade = 7,69%). Além disso, os carotenoides todo-*trans*-luteína, *cis*-luteína, *cis*-α-caroteno, di-*cis*-β-caroteno, e todo-*trans*-β-caroteno não foram identificados na fração micelar. A respeito do fruto inteiro de *P. jaboticaba*, nota-se bioacessibilidade de 21,36% do teor total de carotenoides, sendo que os teores de todo-*trans*-luteína (Bioacessibilidade = 1,04%) e fitoeno (Bioacessibilidade = 26,47%) reduziram. Contudo, foram identificados dois novos carotenoides na fração micelar: *cis*-γ-caroteno e fitoflueno. Deste modo, foi possível respondermos ao nosso problema de pesquisa e discutir o efeito da digestão no perfil e teor de carotenoides em polpa de *M. flexuosa* e *S. cumini* e fruto inteiro de *P. jaboticaba*.

**Palavras-chave:** Alimento Funcional; Carotenoides; Compostos Bioativos; Composição Proximal; Nutrientes.

## **Summary**

The determination of the bioaccessible fraction provides valuable information regarding the recommended dosage of each corresponding compound in its food source, in order to ensure adequate nutritional efficacy. Thus, this work aimed to be a pioneer in the study of carotenoids bioaccessibility from the pulp of *M. flexuosa* and *S. cumini*, and in whole fruit of *P. jaboticaba*. Digestion was divided into three phases: oral, gastric and intestinal, in which temperature, pH, time and agitation were controlled, in addition to simulating the enzymatic conditions to which the food is exposed. The final solution (chyme) was separated for carotenoid extraction or was centrifuged, separating the micellar fraction, which was also used to extract carotenoids, which were extracted with methanol. It was observed that the *in vitro* digestion process showed a significant reduction in the total levels of carotenoids for all fruits. Originally, the following compounds were identified in *M. flexuosa* pulp: all-*trans*-phytoene, all-*trans*-phytوفuen, *cis*-β-carotene, all-*trans*-β-carotene and all-*trans*-β-carotene; totaling 143.49 µg.g<sup>-1</sup>. All-*trans*-lutein, all-*trans*-phytoene, *cis*-phytوفuen, *cis*-α-cryptoxanthin, all-*trans*-α-cryptoxanthin and all-*trans*-β-cryptoxanthin were identified in the chyme; totaling 7.26 µg.g<sup>-1</sup>. Finally, in the micellar fraction it was only possible to identify 5,8-epoxy-β-cryptoxanthin, in a concentration of 0.11 µg.g<sup>-1</sup>, so only 0.077% of the carotenoids total are bioaccessible after the simulated

digestion. The bioaccessible fraction of carotenoids in *S. cumini* pulp is 9.30%, with an increase in all-*trans*-β-carotene (bioaccessibility = 133.33%) and a reduction in 15-*cis*-β-carotene (bioaccessibility = 20%) and phytoene (bioaccessibility = 7.69%). In addition, all-*trans*-lutein, cis-lutein, cis-α-carotene, di-*cis*-β-carotene, and all-*trans*-β-carotene carotenoids were not identified in the micellar fraction. Regarding the whole fruit of *P. jaboticaba*, bioaccessibility of 21.36% of the total carotenoid content was noted, and the levels of all-*trans*-lutein (Bioaccessibility = 1.04%) and phytoene (Bioaccessibility = 26.47%) have reduced. However, two new carotenoids were identified in the micellar fraction: cis-γ-carotene and phytofluene. In this way, it was possible to answer our research problem and discuss the effect of digestion on the profile and content of carotenoids in pulp of *M. flexuosa* and *S. cumini* and whole fruit of *P. jaboticaba*.

**Keywords:** Functional Food; Carotenoids; Bioactive compounds; Proximal Composition; Nutrients.

## LISTA DE TABELAS

<b>Artigo 1</b>	<b>Nutritional Properties of Buriti (<i>Mauritia genus</i>) and Health Benefits ....</b>	16
Tabela 1	Proximate composition (g.100 g <sup>-1</sup> , fresh weight) of <i>M. flexuosa</i> pulp ...	23
Tabela 2	Mineral composition (mg.100 g <sup>-1</sup> , fresh weight) of <i>M. flexuosa</i> pulp ...	23
Tabela 3	Fatty acid composition <sup>1</sup> (g.100 g <sup>-1</sup> of total lipids) of <i>Mauritia flexuosa</i>	25
Tabela 4	Carotenoid profile <sup>1</sup> (μg.g <sup>-1</sup> ) and vitamin A value (RE.100 g <sup>-1</sup> ) of buriti ( <i>Mauritia vinifera</i> ) .....	30
Tabela 5	Phenolic compounds of <i>M. flexuosa</i> pulp (μg.g <sup>-1</sup> , dry weight) .....	33
Tabela 6	Summary of experimental studies investigating the effects of buriti on health	36
<b>Artigo 2</b>	<b>Jambolan (<i>Syzygium cumini</i> (L.) Skeels): A review on its nutrients, bioactive compounds and health benefits .....</b>	59
Tabela 1	Nutritional composition of <i>S. cumini</i> .....	61
Tabela 2	Anthocyanins of <i>S. cumini</i> pulp and peel .....	61
Tabela 3	Non-anthocyanins phenolic compounds (mg/100 g) of <i>S. cumini</i> pulp and peel	63
Tabela 4	Carotenoids (μg/g) of <i>S. cumini</i> pulp and peel .....	64
Tabela 5	Summary of experimental studies (animal models) investigating the effects of jambolan supplementation on health .....	67
<b>Artigo 3</b>	<b>Bioactive Compounds of Jaboticaba (<i>Plinia</i> sp.): A Systematic Review</b>	73
Tabela 1	Proximate composition (g.100 g <sup>-1</sup> , dry weight) of jaboticaba .....	82
Tabela 2	Mineral composition (mg.100 g <sup>-1</sup> , dry weight) of jaboticaba .....	83
Tabela 3	Phenolic compounds identified in jaboticaba .....	85
Tabela 4	Phenolic compounds (mg.100 g <sup>-1</sup> , d. w.) quantified in jaboticaba .....	87
Tabela 5	Phenolic compounds (mg.g <sup>-1</sup> , d. w.) quantified in extracts of jaboticaba	89
Tabela 6	Volatile organic compounds of jaboticaba (mg.100 g <sup>-1</sup> , d. w.)	102
<b>Artigo 4</b>	<b>Bioacessibilidade de carotenoides em <i>M. flexuosa</i> por digestão <i>in vitro</i> .....</b>	119
Tabela 1	Tempo de retenção (t <sub>R</sub> ) em coluna C <sub>30</sub> , UV-visível (% III/II; % A <sub>B</sub> /II; λ <sub>max</sub> ) e espectroscopia de massa encontrados em polpa de <i>M. flexuosa</i> (fruto, quimo e fração micelar) em HPLC-DAD-MS.....	134
<b>Artigo 5</b>	<b>Bioacessibilidade de carotenoides em polpa de <i>Syzygium cumini</i> e fruto inteiro de <i>Plinia jaboticaba</i> (Vell.) Berg por digestão <i>in vitro</i> ..</b>	151
Tabela 1	Nutrientes (g.100 g <sup>-1</sup> ) e valor energético total (VET, em Kcal) em polpa de <i>S. cumini</i> e fruto inteiro de <i>P. jaboticaba</i> , base úmida .....	163
Tabela 2	Tempo de retenção (t <sub>R</sub> ) em coluna C <sub>30</sub> , UV-visível (% III/II; % A <sub>B</sub> /II; λ <sub>max</sub> ) e espectroscopia de massa encontrados em polpa de <i>S. cumini</i> (fruto, quimo e fração micelar) em HPLC-DAD-MS .....	170
Tabela 3	Tempo de retenção (t <sub>R</sub> ) em coluna C <sub>30</sub> , UV-visível (% III/II; % A <sub>B</sub> /II; λ <sub>max</sub> ) e espectroscopia de massa encontrados em fruto inteiro de <i>P. jaboticaba</i> (fruto, quimo e fração micelar) em HPLC-DAD-MS.....	171

## SUMÁRIO

<b>INTRODUÇÃO .....</b>	8
<b>REFERÊNCIAS.....</b>	12
<b>CAPÍTULO I - REFERENCIAL TEÓRICO .....</b>	15
Artigo 1 - Nutritional Properties of Buriti ( <i>Mauritia genus</i> ) and Health Benefits .....	16
Artigo 2 - Jambolan ( <i>Syzygium cumini</i> (L.) Skeels): A review on its nutrients, bioactive compounds and health benefits.....	59
Artigo 3 - Bioactive Compounds of Jaboticaba ( <i>Plinia sp.</i> ): A Systematic Review.....	73
<b>CAPÍTULO II - BIOACESSIBILIDADE DE CAROTONEIDES DE BURITI, JAMBOLÃO E JABUTICABA .....</b>	118
Artigo 4 - Bioacessibilidade de carotenoides em <i>M. flexuosa</i> por digestão <i>in vitro</i> .....	119
Artigo 5 - Bioacessibilidade de carotenoides em polpa de <i>Syzygium cumini</i> e fruto inteiro de <i>Plinia jaboticaba</i> (Vell.) Berg por digestão <i>in vitro</i> .....	151
<b>CONSIDERAÇÕES FINAIS.....</b>	182

## INTRODUÇÃO

Os compostos bioativos são produzidos pelas plantas como metabólitos secundários. Estes compostos são conhecidos pelo seu potencial efeito farmacológico ou toxicológico em homens e animais. Nas plantas, desempenham funções importantes como proteção contra a ação dos radicais livres produzidos durante a fotossíntese, atração de polinizadores, dispersão de sementes e sinalização celular. Ademais, os compostos bioativos podem ser categorizados de acordo com as classes químicas, sendo divididos em carotenoides, compostos fenólicos como flavonóides antociânicos e não antociânicos ácidos fenólicos e taninos, terpenos, resinas, ligninas, alcalóides, peptídeos, proteínas, dentre outros (BERNHOFT, 2010).

Os carotenoides são tetraterpenos com ligações duplas conjugadas. Divididos em carotenos e xantofilas, estes compostos são pigmentos lipossolúveis amplamente difundidos no reino vegetal, sendo responsáveis, principalmente, pelas cores amarela, vermelha e laranja (MAOKA, 2019). Sua função principal está relacionada com a captação de luz e extinção de radicais livres. Muitos destes compostos podem ser absorvidos e armazenados em tecidos animais (BERNHOFT, 2010). A luteína e a zeaxantina, por exemplo, se acumulam na mácula humana, servindo de filtro à passagem da luz azul, o licopeno pode ser encontrado na próstata de humanos e o  $\beta$ -caroteno no tecido epitelial (BERNHOFT, 2010; MA et al., 2012). No entanto, alguns compostos não ficam disponíveis para absorção intestinal, ao serem degradados pela acidez estomacal, como anteraxantina, neoxantina, violaxantina e epoxy-luteína (MAOKA, 2019). Os carotenóides mais discutidos e estudados são aqueles que podem ser úteis na síntese endógena de vitamina A, como  $\beta$ -caroteno,  $\alpha$ -caroteno e  $\beta$ -criptoxantina (BERNHOFT, 2010; MAOKA, 2019).

Deste modo, para que estes compostos forneçam seus benefícios ao organismo humano é necessário que estejam biodisponíveis, sendo efetivamente absorvidos pelo intestino e migrem através da corrente sanguínea, chegando aos tecidos-alvos. A biodisponibilidade compreende os mecanismos de digestão e absorção gastrointestinais, o metabolismo, além da distribuição dos compostos da dieta ou seus metabólitos até tecidos onde serão armazenados ou prontamente utilizados. Dessa forma, este termo engloba outros dois termos: bioacessibilidade e bioatividade. A bioacessibilidade se refere às fases iniciais, de separação do composto da matriz alimentar, as transformações digestivas, a captação intestinal e o metabolismo pré-sistêmico. Por outro lado, a bioatividade corresponde à absorção e transporte pelos tecidos-alvos, metabolismo e resposta fisiológica (THAKUR et al., 2020).

A digestão humana é um mecanismo complexo que envolve muitas etapas, através das quais o alimento sofre diversas transformações até que o nutriente ou composto bioativo seja completamente hidrolisado e libere seus monômeros, que ficarão disponíveis para absorção. A matriz alimentar sofre sua fragmentação, sobretudo, na boca e estômago, enquanto a digestão enzimática e absorção de nutrientes ocorrem no intestino delgado (GUERRA et al., 2012).

A determinação da fração biodisponível fornece informações valiosas a respeito da dosagem recomendada de cada composto e a fonte alimentar correspondente, de maneira a garantir a adequada eficácia nutricional (FERNÁNDEZ-GARCÍA; CARVAJAL-LÉRIDA; PÉREZ-GÁLVEZ, 2009). Assim, ao longo das últimas duas décadas, têm-se desenvolvido várias técnicas para simular os eventos fisiológicos e físico-químicos envolvidos no processo digestivo, sendo crucial expor a matriz alimentar a cada etapa da digestão, respeitando-se o tempo de trânsito intestinal, o pH, as enzimas envolvidas no processo e os movimentos peristálticos (GUERRA et al., 2012).

Fatores dietéticos (concentração de lipídeos e fibras, por exemplo), conteúdo e tipo de carotenoides, localização do carotenoide no tecido vegetal, interações entre carotenoides, tamanho de partícula de alimento, tratamento térmico, e características do sujeito podem influenciar na bioacessibilidade e biodisponibilidade de carotenoides. Portanto, mesmo quando estes compostos estão em quantidades relevantes, sua utilização pode ser insatisfatória (PRIYADARSHANI, 2017).

Além disso, considerando as grandes variações entre os compostos bioativos, e o grande número de espécies onde podem ser encontrados, é necessário construir uma abordagem padrão e integrada para extraer estes compostos. Assim, os métodos de extração de compostos bioativos a partir de plantas e alimentos vêm sendo desenvolvidos ao longo dos anos (LEFEBVRE; DESTANDAU; LESELLIER, 2021).

As técnicas mais antigas de extração de compostos consistem na simples maceração do alimento em contato com um solvente (água, álcool, óleo, etc.), que é escolhido, por semelhança de polaridade e cinética de interação com a matriz alimentar (AZMIR et al., 2013; LEFEBVRE; DESTANDAU; LESELLIER, 2021). Já as técnicas mais recentes se baseiam no uso de equipamentos simples como banho de ultrassom, vórtex e centrífuga até mais sofisticados como extratores com microondas e sondas de ultrassom, por exemplo. Em todos os casos, é natural que o solvente desempenhe o papel mais importante nestes procedimentos de extração, devido à sua alta seletividade (LEFEBVRE; DESTANDAU; LESELLIER, 2021). Todavia, outros fatores podem influenciar no rendimento do extrato, como a relação entre a

massa do produto e o volume do solvente, número de etapas, e pH (DORTA; LOBO; GONZÁLEZ, 2013).

O buriti (*Mauritia flexuosa*) é o fruto cuja polpa possui os maiores teores de  $\beta$ -caroteno, além de apresentarem teores consideráveis de  $\alpha$ -caroteno e  $\gamma$ -caroteno (RODRIGUEZ-AMAYA, 1999). Assim, o fruto pode apresentar relevante aplicação de modo a prevenir degeneração macular causada por dano oxidativo, relacionado à falta de vitamina A, dentre outras comorbidade (ARUNKUMAR; GORUSUPUDI; BERNSTEIN, 2020). Os teores de carotenoides totais da polpa de buriti podem variar entre 349,9 e 632,2  $\mu\text{g/g}$  de fruto fresco de acordo com a origem do fruto (CÂNDIDO; SILVA; AGOSTINI-COSTA, 2015; NASCIMENTO-SILVA; SILVA; SILVA, 2020). Outros compostos bioativos que pode ter relevante ação antioxidante são os fenólicos, e estes podem ser encontrados em concentrações significativas neste fruto (360,08 a 495,87 mg ácido gálico equivalente/100 g) (CÂNDIDO; SILVA; AGOSTINI-COSTA, 2015; NASCIMENTO-SILVA; SILVA; SILVA, 2020), destacando-se a presença de ácido protocatecúrico, ácido clorogênico, epicatequina, luteolina e catequina (BATAGLION et al., 2014). Entretanto, poucos estudos que descreveram o perfil de compostos fenólicos e carotenoides em polpa de buriti e não foram encontrados trabalhos que descrevessem a bioacessibilidade de destes compostos nesta matriz alimentar.

O jambolão (*Syzygium cumini*) é um fruto nativo da Ásia, mas que se disseminou por todo o globo, podendo ser encontrado na África e América Latina, uma vez que se adapta bem a climas tropicais e subtropicais (SABINO; BRITO; SILVA-JUNIOR, 2018). A polpa de jambolão é amplamente conhecida pela presença de teores consideráveis de antocianinas, que podem variar entre 28 e 1318 mg/100 g, dependendo do estágio de maturação e região de procedência (LESTARIO et al., 2017). Deste modo, o fruto se destaca pelos teores significativos de compostos fenólicos (995 a 1117 mg AGE/100 g) (REYNERTSON et al., 2008; RUFINO et al., 2010), principalmente ácido gálico e elágico (LESTARIO et al., 2017). Foram encontrados poucos estudos que descreveram o perfil de carotenoides em polpa de jambolão na literatura científica (FARIA; MARQUES; MERCADANTE, 2011; BARCIA et al., 2012). Entretanto, não foram encontrados estudos que descreveram a bioacessibilidade de compostos fenólicos e carotenoides em polpa de jambolão.

Fruto da mesma família e espécie do jambolão, a jabuticaba (*Plinia* sp.), destaca-se pelos elevados teores de compostos fenólicos totais (744 mg AGE/100 g), principalmente ácido elágico (311 mg AGE/100 g) (ABE; LAJOLO; GENOVESE, 2011; SALOMÃO et al., 2018). Todavia, estudos a respeito do seu conteúdo e perfil de carotenoides são escassos, assim como

a bioacessibilidade destes compostos. De acordo com Inada et al. (2020), 47% dos compostos fenólicos totais ficam disponíveis após digestão gástrica, sobretudo cianidina-3-O-glucosídeo, ácido elágico e ácido gálico. Após a fase intestinal a bioacessibilidade das antocianinas reduz em 25% e do ácido elágico aumenta 74%.

Portanto, optou-se por trabalhar com tais frutos uma vez que se destacam nos teores de compostos bioativos, além de terem sido encontrados poucos ou nenhum estudo com o mesmo propósito. Assim, este trabalho pretende ser pioneiro no estudo de bioacessibilidade de carotenoides de polpa de buriti e de jambolão, e em fruto inteiro de jabuticaba. Esses dados podem servir de subsídio para aumentar o valor agregado aos frutos, valorizá-los como alimentos funcionais, expandir o seu consumo e ter consequências diretas na segurança econômica e alimentar das populações locais envolvidas na sua coleta e distribuição.

A partir desses pressupostos, espera-se responder o seguinte questionamento: qual é a fração bioacessível de carotenoides de buriti, jambolão e jabuticaba? Para responder o problema de pesquisa, adota-se como objetivo geral desta tese determinar e descrever a fração bioacessível de carotenoides em polpa de buriti, polpa de jambolão e fruto inteiro da jabuticaba. Especificamente, espera-se, também, realizar revisões bibliográficas a respeito dos frutos analisados no presente estudo, descrevendo sua composição nutricional, perfil e teor de compostos bioativos e seus efeitos na saúde, de modo a elucidar as principais lacunas no estudo de buriti, jambolão e jabuticaba. Além disso, são, também, objetivos específicos descrever a composição proximal dos frutos, e seu perfil de carotenoides, assim como quantificar sua fração bioacessível.

Deste modo, espera-se defender a tese que os frutos buriti, jambolão e jabuticaba apresentam teores consideráveis de carotenoides bioacessíveis. Para tanto, o trabalho foi organizado em dois capítulos. O primeiro capítulo é composto pelas revisões bibliográficas, que descrevem a composição em macronutrientes e minerais, o conteúdo e perfil de lipídeos e ácidos graxos, o teor carotenoides, e os efeitos à saúde dos frutos buriti, jambolão e jabuticaba.

O segundo capítulo comprehende os artigos referentes à composição proximal dos frutos analisados no presente estudo e descrever o perfil de carotenoides dos três frutos em análise e sua respectiva fração bioacessível. Diferentemente do capítulo anterior, este capítulo é composto por apenas dois artigos, uma vez que se julgou mais coerente comparar o perfil e bioacessibilidade de carotenoides de jambolão e jabuticaba, devido às grandes semelhanças entre os frutos.

No campo metodológico, as pesquisas terão abordagem quali-quantitativas, a partir de fundamentos interdisciplinares. Especificamente, cada capítulo do trabalho exigiu um conjunto de técnicas particulares. Portanto, a metodologia será descrita individualmente em cada artigo científico.

Considerando esses aportes iniciais, esta pesquisa guarda sintonia com a linha de pesquisa “Propriedades Físicas, Químicas, Moleculares, Microbiológicas, Nutricionais e Funcionais de Alimentos”, no âmbito do Programa de Pós-Graduação em Ciência e Tecnologias de Alimentos da Universidade Federal de Goiás, tendo o papel de contribuir academicamente para o desenvolvimento da área, servindo de subsídio para pesquisas futuras.

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# CAPÍTULO I

## REFERENCIAL TEÓRICO

**Artigo 1:** Nutritional Properties of Buriti (*Mauritia genus*) and Health Benefits – Submetido à revista: “*Journal of Cleaner Production*”.

**Artigo 2:** Jambolan (*Syzygium cumini* (L.) Skeels)): A review on its nutrients, bioactive compounds and health benefits – Publicado na revista “*Journal of Food Composition and Analysis*”.

**Artigo 3:** Bioactive Compounds of Jaboticaba (*Plinia* sp.): A Systematic Review – Submetido à revista: *Journal of Food Composition and Analysis*

## **Artigo 1**

### **Nutritional Properties of Buriti (*Mauritia* genus) and Health Benefits**

Submetido à revista: Journal of Cleaner Production

Guia para autores: <https://www.elsevier.com/journals/journal-of-cleaner-production/0959-6526/guide-for-authors>

## **Nutritional Properties of Buriti (*Mauritia* genus) and Health Benefits**

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### **Abstract**

In order to identify strategies to encourage the cultivation of buriti and studies on its nutritional quality, as well as applications in human health and potential for pharmaceutical use, this review proposes a general view regarding these topics in buriti pulp. Therefore, the search was carried out in the databases Science Direct, Scopus and MEDLINE from the beginning of each database until June 23, 2021. Buriti pulp stands out for its considerable levels of lipids, especially palmitic and oleic acids, besides the high levels of tocopherols and phytosterols. Buriti pulp is rich in carotenoids, mainly  $\beta$ -carotene, and phenolic compounds such as protocatecuric acid, chlorogenic acid, epicatechin, luteolin and catechin. The fruit may have the potential to be applied to decrease the risk of developing inflammatory diseases and as an antimicrobial agent. Moreover, taking into consideration the data available in the literature, this study was pioneer in proposing the pathway of carotenoid synthesis in this fruit.

**Keywords:** Functional food; Health benefits; Medicinal food; Pharmacognostical; Physicochemical.

## 1. Introduction

Buriti, miriti, carandá-guaçú, carandaí-guaçú, muriti, palmeira-buriti, palmeira-dos-brejos, mariti, bariti, meriti or dembyriti, which in Tupi-Guarani (indigenous language) means “palm tree that emits liquid” (EMBRAPA, 2006). It is known that buriti is the palm tree of the *Arecaceae* family, genus *Mauritia*, but there are still some controversies in the literature regarding the species. Some authors believe in the existence of two species, *M. flexuosa* and *M. vinifera*, the first from Peru and the second from Brazil, but specialists in Brazilian botany report the existence of only one species *Mauritia flexuosa* Linnaeus filius (Santos, 2005, EMBRAPA, 2006). As this discussion is not part of this work, we will respect the choice of the original authors.

Buriti is a palm tree that inhabits paths and gallery forests, in flooded places and springs. It is widely distributed in South America, being found mainly in the Amazon region of Peru, Brazil, Colombia, Venezuela, Guyanas, Trinidad and Tobago, Ecuador and Bolivia (EMBRAPA, 2006).

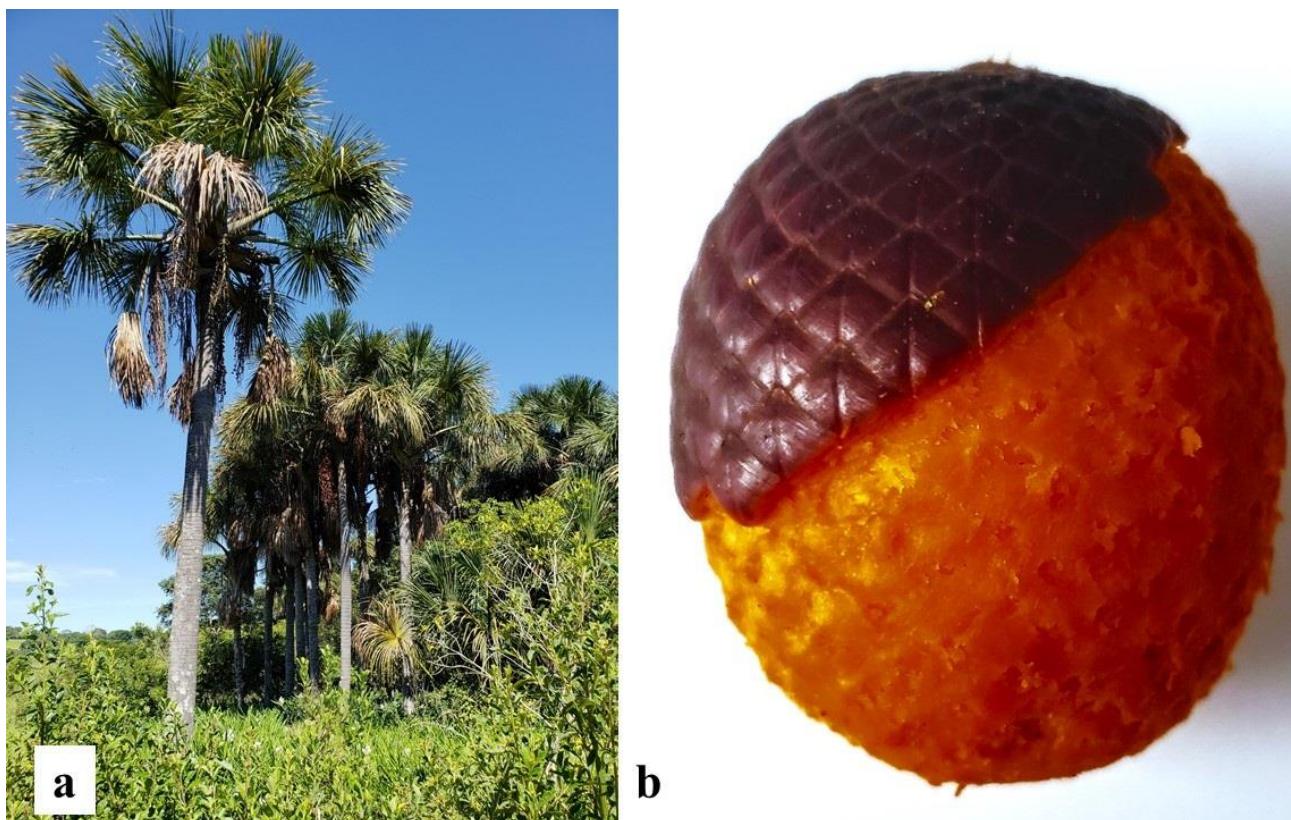
This palm tree reaches between 35 and 40 m in height, composed of an erect, smooth and cylindrical stem, ranging from 30 to 60 cm in diameter. The spherical crown has long leaves, which can measure up to 6 m, distributed in groups of 10 to 20 leaves. The buriti fruit (Fig. 1) are drupoid and oblong-ellipsoid in shape, measures between 5 and 7 cm in length and 4 to 5 cm in width, weighing between 40 and 85 g. It presented its exocarp as rigid and juxtaposed scales, with a reddish-brown color. The mesocarp, or edible pulp, is orange and has a sweet and earthy taste, with an oily texture and pasty consistency, while the inner endocarp is white and fibrous and covers the integument that lines the endocarp (EMBRAPA, 2006, Santos, 2005, Silva et al., 2014).

Flowering peaks at the interface between the rainy and dry seasons, usually at the end of floods, while fruiting occurs during the rainy season, however only 20% of females fruit annually (Virapongse et al., 2017). Fruit production is influenced by plant leaf size, soil moisture, temperature and precipitation. Plant leaf size, soil moisture, temperature and precipitation influence fruit production. The fruit is climacteric, and the optimum harvest point occurs 210 days after anthesis, the final stage of flowering, with the highest levels of carotenoids observed 8 days after fruit drop (Milanez et al., 2016 and 2018).

Some indigenous communities use fruit pulp, oil, fiber, leaves, petioles, larvae found on the decaying trunk, sap, palm heart, seeds and roots for construction, food,

crafts, rituals, cultural activities, medicines and household utensils. The buriti trade encourages the local population, generating a source of primary and supplementary income for families where income is scarce and vulnerable. Although the extraction of the fruit is frequent and many artisans use the leaves in the production of toys, isn't the primary income of the family (EMBRAPA, 2006, Sousa, Vieira-da-Silva, & Barros, 2018, Virapongse et al., 2017).

To identify strategies to encourage the cultivation of buriti, studies on nutritional quality, applications in human health and potential for pharmaceutical and cosmetic use are of paramount importance. Thus, this review proposes a general view regarding the nutritional and functional aspects and the health benefits of the pulp of buriti.



**Fig. 1.** *M. flexuosa*: (a) mature tree; (b) mature fruit.

## 2. Method of research

This review was carried out according to the methodology described by Brasil (2012). Therefore, to describe the nutritional composition of buriti pulp, highlighting its bioactive compounds and its effect on health, the following combined terms were used: "*Mauritia flexuosa*" OR "buriti". The indexing terms used are in the platforms MeSH

(Medical Subject Headings) and Emtree. The search was carried out in the databases Science Direct, Scopus and MEDLINE (PubMed). Filters were not used in relation to study types or year. Thus, the search was carried out from the beginning of each database until June 23, 2021 (date of the last search for all databases) and did not impose restrictions on the language of publication.

Were included articles that described the proximate composition; analyzed the profile of fatty acids, carotenoids and phenolic compounds; determined the bioaccessibility of bioactive compounds; and evaluated the effect of oral supplementation or application of pulp or oil of buriti. Other eligible studies were included by searching the reference lists of included studies.

Were excluded studies that described the antioxidant activity by in vitro methods (DPPH, FRAP, ABTS or ORAC); analyzed other parts of the plant than the pulp; reported the thermal properties, rheological properties, and phase transitions from buriti oil only; and carried out studies on encapsulation and production of emulsion, biodiesel or nanoparticles. In cases of studies with duplicate results, the most complete work was selected.

The articles were pre-selected by reading their titles and abstracts, taking into account the eligibility criteria and excluding duplicates. Then, the papers were read in full and used to write this review.

### **3. Results**

#### *3.1. Results of the search*

The 101 articles were found in Science direct, 565 in Scopus and 363 in MEDLINE using the descriptors “*Mauritia flexuosa*” OR “buriti” together, 29, 86 and 16 articles were selected by reading the titles and abstracts by considering inclusion and exclusion factors. After the complete reading and analysis of the articles, 49 articles were selected. Articles were found since 1974, which described the physicochemical aspects of the fruit.

Because of the large number of articles found on the proximate composition and profile of fatty acids in buriti pulp, only studies published in the last 10 years were discussed in this document.

### 3.2. Macronutrients and minerals composition

The relationship between genotype and phenotype is well understood in the scientific literature. However, when evaluating four populations of buriti native from different regions of the Brazilian Middle North Region, Dias et al. (2017) noted that the phenotypic and genotypic estimates showed high correlation for all pairs of proposed combinations, except for the volume and polar diameter of the fruits. However, the effect of genotype was greater than phenotype. Thus, the authors concluded that the environment did not exert a significant influence on the point of overcoming the effect of the genotype. This may justify the slight variations observed in the proximate composition of the buriti pulp analyzed in the different studies (Table 1), even if they are native to distinct regions.

Buriti pulp has high moisture contents (50.5 to 79.3 g.100 g<sup>-1</sup>) (Table 1), which reduces its resistance to the proliferation of pathogens, since the high-water content in food has a direct correlation with the proliferation of microorganisms, being a problem in the manufacture of by-products (Syamaladevi et al., 2016). When compared to other tropical fruits, buriti stands out mainly for its high concentrations of total lipids (6.1 to 20.9 g.100 g<sup>-1</sup>), being superior to ingá (*Inga alba*; 0.1 g.100 g<sup>-1</sup>), pitomba (*Talisia esculenta*; 0.15 g.100 g<sup>-1</sup>), cagaita (*Eugenia dysenterica*; 0.3 to 0.5 g.100 g<sup>-1</sup>), araticum (*Annona crassiflora*; 0.9 to 2.5 g.100 g<sup>-1</sup>), arassa (*Psidium firmum*; 1.0 g.100 g<sup>-1</sup>), murici (*Byrsonima verbascifolia*; 2.2 g.100 g<sup>-1</sup>), and mangaba (*Hancornia speciosa*; 2.1 to 2.3 g.100 g<sup>-1</sup>) (Silva & Fonseca, 2016). Besides, it presents lipid values like those reported for bocaiuva (*Acrocomia aculeata*; 13.5 g.100 g<sup>-1</sup>) and lower than those described pequi (*Caryocar brasiliense*; 33.3 g.100 g<sup>-1</sup>) (Schiassi et al., 2018, Silva & Fonseca, 2016). Despite not being fruits of the same family, this comparison is relevant when considering the availability and access of the local population to the fruits.

Buriti pulp has total carbohydrate contents (5.7 to 25.5%, f.w.) within the expected range for fruits, having similar results to the tropical fruits mentioned above, which vary between 4.25 and 35.40 g.100 g<sup>-1</sup> (Schiassi et al., 2018, Silva & Fonseca, 2016). Among these carbohydrates, some monosaccharides can be found, such as ramnose (11.3 to 20.5 mol%), fucose (0.8 mol%), arabinose (163.1 to 380.6 mol%), xilose (9.0 to 156.6 mol%), manose (2.8 to 8.2 mol%), galactose (21.9 to 23.2 mol%), glucose (3.0 to 117.7 mol%), and polysaccharides, like 2,3,5-Me3-Ara (3.0 mol%), 2,3-Me2-Ara (37.0 mol%), 2,3,4,6-Me4-Glc (1.5 mol%), 2,4,6-Me3-Glc (12.0 mol%), and 2,3,6-Me3-Glc (46.5 mol%) (Cantu-Jungles et al., 2015, Cordeiro et al., 2015). According to Schiassi et al. (2018), the

total content of pectin ( $0.59 \pm 0.02$  g) and soluble pectin ( $0.49 \pm 0.01$  g) of buriti pulp presents values similar to arassa (*Psidium firmum*), higher than cagaita (*Eugenia dysenterica*) and lower than araticum (*Annona crassiflora*).

The total pectin content in buriti pulp significantly reduces after harvest until the tenth day of storage, while the soluble solids increase. In addition, the fruit storage process causes changes in the solubilization of peptic polysaccharides, generating depolymerized compounds such as soluble pectin. Thus, as the buriti ripening process progresses, there is an increase in the levels of galacturonic acid from 47.4% to 57.6% for fruits that were harvested in the immature phase, from 49.0% to 60% for fruits harvested in the initial stage of maturation and from 51.3% to 56.4% for fruits harvested in the final stage of ripening (Milanez et al., 2018).

Regarding the minerals present in buriti pulp, it is possible to observe large variations between studies, mainly for potassium and iron (Table 2). However, it is possible to verify that buriti pulp stands out for its considerable manganese contents, since 100 g of the fruit can offer between 204 and 565% of the Recommended Dietary Allowance (RDA) for adults, as well as magnesium (11 to 31% of the RDA), potassium (8 to 40% of the RDA) and iron (2 to 35% of the RDA) (IOM, 2006, National Academies of Sciences, Engineering, and Medicine, 2019).

When compared to other tropical fruits, once again, buriti pulp stands out for its manganese concentrations, which can be two to four times higher than that of fruits such as caja (*Spondias mombin*;  $0.42 \pm 0.01$  mg.100 g<sup>-1</sup>), araticum ( $0.60 \pm 0.01$  mg.100 g<sup>-1</sup>), and cagaita ( $1.56 \pm 0.07$  mg.100 g<sup>-1</sup>) (Nascimento et al., 2020). Despite offering less than 10% of the RDA (IOM, 2011) of calcium for adults, buriti pulp has higher levels of this mineral than araticum ( $9.35 \pm 0.86$  mg.100 g<sup>-1</sup>), cagaita ( $15.35 \pm 2.23$  mg.100 g<sup>-1</sup>), and caja ( $23.66 \pm 3.12$  mg.100 g<sup>-1</sup>) (Nascimento et al., 2020).

1 **Table 1.**2 Proximate composition (g.100 g<sup>-1</sup>, fresh weight) of *M. flexuosa* pulp.

Reference	Moisture	Protein	Lipids	Ashes	Dietary fibers	Carbohydrates	Energy (kcal.100 g <sup>-1</sup> )
Nascimento-Silva et al. (2020) – Goiás, Br	70.00 ± 0.35	1.85 ± 0.01	9.03 ± 0.19	1.18 ± 0.01	7.17 ± 0.33	10.60	131.07
Nascimento-Silva et al. (2020) – Pará, Br	58.52 ± 0.58	2.14 ± 0.02	18.91 <sup>a</sup> ± 0.48	1.04 ± 0.00	8.16 ± 0.38	11.22	223.70
Berni et al. (2019) – São Paulo, Br	63.20	0.68	19.20	0.92	10.33	5.70	-
Schiassi et al. (2018) – São Paulo, Br	79.35 ± 0.99	1.43 ± 0.38	7.72 ± 0.59	1.01 ± 0.03	6.02 ± 0.30	4.47 ± 0.90	93.08
Lescano et al. (2018) – Mato Grosso, Br	73.45 ± 0.43	4.30 ± 0.09	13.75 ± 0.56	1.41 ± 0.15	8.32 ± 1.25	3.08 ± 0.66	-
Cândido & Silva (2017) – Goiás, Br	74.47 ± 0.11	1.87 ± 0.01	6.15 ± 0.26	1.12 ± 0.04	6.69 ± 0.08	9.70 ± 0.41	101.58
Cândido & Silva (2017) – Pará, Br	64.45 ± 0.20	2.42 ± 0.05	14.28 ± 0.39	0.93 ± 0.01	6.61 ± 0.01	11.31 ± 0.54	184.60
Aguiar & Souza (2017) – Amazonas, Br	55.00 ± 0.01	2.35 ± 0.00	22.17 ± 0.30	1.61 ± 0.00	-	18.87 ± 0.30	284.40
Sandri et al. (2017) – Mato Grosso, Br	59.69 ± 0.64	2.97 ± 0.39	20.92 ± 0.72	1.04 ± 0.04	8.56 ± 0.15	7.28 ± 0.07	229.28
Darnet et al. (2011) – Pará, Br	50.50 ± 1.14	3.70 ± 0.02	19.00 ± 0.72	0.60 ± 0.00	22.80 ± 0.38	26.20	240.45
Manhães & Sabaa-Srur (2011) – Pará, Br	62.93 ± 0.12	2.10 ± 0.19	13.85 ± 0.69	0.94 ± 0.06	5.17 ± 1.16	8.25	166.36
Carneiro & Carneiro (2011) – Caatinga, Br	54.35 ± 0.15	1.30 ± 0.00	18.16 ± 1.52	0.66 ± 0.01	-	25.53	270.00

3 Results are expressed as mean ± standard deviation.

4

5 **Table 2.**6 Mineral composition (mg.100 g<sup>-1</sup>, fresh weight) of *M. flexuosa* pulp.

Mineral	Vásquez-Ocmín et al. (2010)			Cândido & Silva (2017)		Schiassi et al. (2018) São Paulo, Br	Lescano et al. (2018) Mato Grosso, Br	Nascimento et al. (2020) Minas Gerais, Br
	Aucayo, Pe	Libertad, Pe	Centro Union, Pe	Goiás, Br	Pará, Br			
Zinc	1.3 ± 0.1	1.2 ± 0.0	0.7 ± 0.0	0.7 ± 0.0	0.3 ± 0.0	-	-	1.1 ± 0.1
Calcium	44.3 ± 0.6	34.8 ± 5.4	27.2 ± 0.8	89.1 ± 0.0	44.1 ± 0.0	37.8 ± 1.5	3.1 ± 0.1	36.9 ± 0.6
Copper	0.6 ± 0.1	0.9 ± 0.0	0.4 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	-	-	0.4 ± 0.1
Sodium	231.4 ± 39.1	91.6 ± 5.7	80.2 ± 2.1	2.1 ± 0.0	2.1 ± 0.0	-	-	6.3 ± 0.4
Magnesium	60.5 ± 4.8	67.6 ± 6.0	52.4 ± 5.5	36.5 ± 0.0	33.9 ± 0.2	-	1.3 ± 0.1	37.3 ± 2.9
Manganese	7.3 ± 0.1	13.0 ± 0.6	5.8 ± 0.0	-	-	14.3 ± 0.5	-	4.7 ± 0.3
Potassium	910.9 ± 30.2	1042.9 ± 3.6	809.9 ± 22.9	218.4 ± 0.1	211.0 ± 0.3	183.5 ± 10.0	-	-
Iron	4.2 ± 0.4	6.3 ± 0.6	1.5 ± 0.2	0.4 ± 0.0	0.5 ± 0.0	0.7 ± 0.2	-	2.4 ± 0.6
Phosphorus	-	-	-	-	-	6.9 ± 0.4	-	-

7 Results are expressed as mean ± standard deviation

### 3.3. Lipid profile

There is no established definition for lipids, but what is known is that the common characteristic these compounds share is the fact that they are insoluble in water. Most lipids have fatty acids as part of their structure or related compounds, such as the corresponding alcohols and sphingosine bases. Fatty acids can be named in a variety of ways, the most recurrent of which is to receive the name of the food where it was found, like oleic acid, which was discovered in olive oil, or palmitic acid, found in palm oil. Another way of naming it is by assigning the name of the researcher who identified it, as with Mead's acid (20:3 n-9). The systematic name is based on the chemical or biochemical arrangement of the molecule (Carvalho & Caramujo, 2018; Gustone, 2012).

Fatty acids can be classified according to the size of the carbon chain or by the presence and quantity of double bonds (Bazinet & Layé, 2014). Short-chain fatty acids contain up to 6 carbon atoms, medium chain atoms between 8 and 12 and long chain over 18 carbons (Huang et al., 2011). Compounds that do not have double bonds between their carbon atoms are called saturated (SFA), while those that have one are monounsaturated (MUFA) and those that have over two are polyunsaturated (PUFA). PUFAs, which contain multiple double bonds between carbon atoms, can be allocated into two families, depending on the position of the double bond at the end of the methyl terminal ( $\omega$ ;  $n$ -) (Bazinet & Layé, 2014).

Palmitic acid (16:0) is the most widely disseminated SFA in nature. It can be detected in vegetable oils, fish oil, and milk and adipose tissue from land animals (Gustone, 2012). Oleic acid (18:1) is the fatty acid most distributed in nature and found in several products. Besides being the biological precursor to all monoene acids and the  $n$ -9 family. Members of the C18 family can be found in most vegetables, while representatives of the C16, C20 and C22 families are identified in fish oil or fat from other creatures. A member of the C18 family, linoleic acid (C18:2  $\omega$ -6) is the most prevailing polyene acid in vegetable oils. Furthermore, it is the prototype for other acids in the same category. Linolenic acid (C18:3  $\omega$ -3) is not a very common acid, but recent discoveries about its functions have attracted the spotlight for this compound. The adequate consumption of  $\omega$ -3 PUFAs can protect the human body against inflammatory diseases, cancer, cardiovascular diseases and other chronic diseases (Gustone, 2012; Saine & Keum, 2018).

**Table 3.**Fatty acid composition<sup>1</sup> (g.100 g<sup>-1</sup> of total lipids) of *Mauritia flexuosa*.

Fatty acids	1	2	3	Goiás, Br <sup>4</sup>	Pará, Br <sup>4</sup>	5	6	7	8	9	10	11
<b>SFA</b>	<b>21.76</b>	<b>21.9</b>	<b>21.0</b>	<b>21.68</b>	<b>17.27</b>	<b>21.37</b>	<b>17.87</b>	<b>21.92</b>	<b>19.98</b>	<b>25.26</b>	<b>18.83</b>	<b>19.7</b>
Valeric acid 6:0	-	-	-	-	-	-	-	-	-	0.0	0.3 ± 0.4	0.3
Caprylic acid 8:0	0.6 ± 0.1	-	-	-	-	-	-	-	-	0.1	-	-
Capric acid C10:0	-	-	-	-	-	-	0.1 ± 0.0	-	-	0.0	-	-
Lauric C12:0	-	-	-	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1	0.0	0.0	-	-
Myristic C14:0	-	-	0.5 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	0.1	0.1	0.1	0.0 ± 0.0	0.1
Pentadecanoic C15:0	-	-	-	0.1 ± 0.0	0.1 ± 0.1	0.1 ± 0.0	-	0.0	0.1	0.0 ± 0.0	-	-
Palmitic C16:0	19.3 ± 0.1	18.9 ± 0.2	19.2 ± 0.1	18.8 ± 0.1	15.2 ± 0.1	17.3 ± 0.1	16.1 ± 0.0	19.8	17.6	22.2	16.4 ± 0.2	17.8
Heptadecanoic C17:0	-	-	-	0.2 ± 0.1	0.2 ± 0.0	0.1 ± 0.0	-	-	0.1	0.1	0.1 ± 0.0	-
Stearic C18:0	1.9 ± 0.1	1.3 ± 0.1	1.3 ± 0.0	2.1 ± 0.1	1.6 ± 0.0	3.3 ± 0.0	1.0 ± 0.0	2.0	1.5	2.5	1.9 ± 0.0	1.5
Arachidic C20:0	-	1.7 ± 0.2	-	0.2 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	0.1 ± 0.0	0.1	0.7	0.2	0.1 ± 0.2	-
Behenic C22:0	-	-	-	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.2 ± 0.0	-	-	0.0 ± 0.0	-	-
Lignoceric C24:0	-	-	-	0.1 ± 0.1	0.1 ± 0.0	0.1 ± 0.0	0.1 ± 0.0	-	-	-	-	-
<b>MUFA</b>	<b>73.32</b>	<b>76.0</b>	<b>65.6</b>	<b>73.03</b>	<b>79.43</b>	<b>70.34</b>	<b>81.86</b>	<b>72.55</b>	<b>78.81</b>	<b>73.05</b>	<b>78.53</b>	<b>75.7</b>
Palmitoleic C16:1	0.3 ± 0.1	-	-	0.3 ± 0.0	0.4 ± 0.0	0.2 ± 0.0	0.5 ± 0.0	0.4	0.3	0.2	0.2 ± 0.0	-
Heptadecenoic acid C17:1	-	-	-	-	-	0.1 ± 0.0	-	-	-	0.1	0.0 ± 0.0	-
Oleic C18:1 ω-9	73.3 ± 0.1	75.7 ± 0.4	65.6 ± 0.0	72.2 ± 0.1	78.6 ± 0.1	69.6 ± 0.2	78.5 ± 1.0	72.1	78.5	72.2	78.1 ± 0.0	75.7
Gadoleic C20:1	-	-	-	0.5 ± 0.0	0.4 ± 0.0	0.4 ± 0.0	-	0.6	0.6	0.3 ± 0.0	-	-
<b>PUFA</b>	<b>4.86</b>	<b>2.1</b>	<b>13.2</b>	<b>5.29</b>	<b>3.30</b>	<b>8.29</b>	<b>2.56</b>	<b>5.53</b>	<b>1.22</b>	<b>1.66</b>	<b>2.65</b>	<b>2.8</b>
Linoleic C18:2 ω-6	2.7 ± 0.1	2.1 ± 0.1	4.9 ± 0.1	3.2 ± 0.1	1.8 ± 0.0	7.3 ± 0.0	1.8 ± 0.0	2.8	1.1	0.5	1.7 ± 0.1	1.7
Linolenic C18:3 ω-3	2.2 ± 0.1	-	8.2 ± 0.1	2.1 ± 0.1	1.4 ± 0.1	1.0 ± 0.0	0.8 ± 0.0	2.2	0.1	1.2	0.9 ± 0.1	1.1
AA C20:4 ω-6	-	-	-	-	-	-	-	-	-	0.1 ± 0.0	-	-
EPA C20:5 ω-3	-	-	-	-	-	-	-	-	-	0.0 ± 0.0	-	-

<sup>1</sup>Values are presented as mean ± standard deviation. MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; SFA: saturated fatty acids; AA: Arachidonic acid; EPA: Eicosapentaenoic acid. References: <sup>1</sup>Manhães & Sabaa-Srur (2011); <sup>2</sup> Darnet et al. (2012); <sup>3</sup> Speranza et al. (2016); <sup>4</sup> Cândido & Silva (2017); <sup>5</sup> Freitas et al. (2017); <sup>6</sup> Lescano et al. (2018); <sup>7</sup> Nobre et al. (2018); <sup>8</sup> Serra et al. (2019); <sup>9</sup> Cruz et al. (2020); <sup>10</sup> Mesquita et al. (2020); <sup>11</sup> Parente et al. (2020).

The arachidonic acid (C20:4  $\omega$ -6) is an important precursor to members of the eicosanoid cascade, such as prostaglandins, thromboxanes, and leukotrienes. It is possible to identify this fatty acid in tiny concentrations of fish oil, but in higher levels of animal phospholipids, such as those found in eggs and liver (Gustone, 2012; Saine & Keum, 2018).

Palmitic and stearic acids are the main SFA within the human brain, while oleic acid is the principal MUFA, and arachidonic (ARA) and docosahexaenoic (DHA) acids are the greatest representative of the PUFA. These compounds can be determined free (non-esterified) or esterified as triglycerides, cholesterol and phospholipids. Among the principal functions of PUFAs in the brain, hypothalamic regulation in hepatic glucose production, food intake, and analgesia stands out (Bazinet & Layé, 2014).

Besides the effects mentioned above, adequate consumption of  $\Omega$ -3 PUFAs can exert a positive action by reverting the microbiota composition in dysbiose, and increase the production of anti-inflammatory compounds, like short-chain fatty acids, also maintaining the intestinal wall integrity (Costantini et al., 2017).  $\omega$ -3 PUFAs have a reasonable effect on atherosclerosis and cardiovascular diseases, through several mechanisms, including the alteration of physical and chemical properties of cellular membranes, and modulation of membrane channels and proteins, regulation of gene expression, modifications in eicosanoid profiles, and conversion of  $\omega$ -3 PUFAs to bioactive metabolites, which may avoid ischemia (Pizzini et al., 2017).

The identification of fatty acids is performed in gas chromatography when comparing their behavior (retention time) with that of similar structures. To determine the structure of a fatty acid it is necessary to define the size of its chain, the existence of branches and functional groups, as well as the presence, quantity, position and configuration of unsaturation and its stereochemical structure. Classical separation procedures include distillation and crystallization. When it comes to PUFAs, one must pay attention to temperature, in order to avoid unwanted changes, such as stereomutation, double bond migration, cyclization and dimerization (Gustone, 2012).

Several studies were located that investigated the fatty acid profile in buriti over the years (Table 3). This fruit is rich in MUFAs (65.6 to 79.43%), mainly oleic acid ( $\omega$ -9), and PUFAs (2.1 to 8.29%), especially Linoleic acid ( $\omega$ -6) and Linolenic ( $\omega$ -3), but a recent study (Mesquita et al., 2020) also mentioned traces of ARA and EPA. Among the SFAs described in the buriti, the levels of palmitic acid (15.2 to 19.73%) stand out, which besides being the main component of the human brain, as previously reported, can be

found in abundance in human milk and play an essential role in the structure and function of the uterus (Agostini et al., 2016). Thus, when the fat acid profile of buriti oil is compared with other oils such as olive oil, it has been observed that they are very similar, since olive oil has the following composition: 79.8% oleic acid, 10.7% palmitic acid, 3.96% linolenic acid and 2.74% stearic acid (González-Hedström et al., 2020).

Regarding the acylglycerol classes, the most abundant compounds in buriti oil are triacylglycerols (88.33 to 93.33%), followed by diacylglycerols (6.66 to 8.02%). The predominant triacylglycerols described in the literature were OOO (33 to 40%), POO (26% to 39%), OLO (11%) and POP (6.5 to 10%) (O: oleic acid; P: palmitic acid; L: linoleic acid) (Freitas et al., 2017; Santos, Marmesat, Brito, Alves, & Dobarganes, 2013; Speranza et al., 2018).

Moreover, this oil has from 1,041 to 1,517  $\mu\text{g.g}^{-1}$  of tocopherol, among them stand out  $\gamma$ -tocopherol (50 to 878  $\mu\text{g.g}^{-1}$ ),  $\beta$ -tocopherol (501 to 687  $\mu\text{g.g}^{-1}$ ),  $\alpha$ -tocopherol (252 to 614  $\mu\text{g.g}^{-1}$ ), and  $\delta$ - tocopherol (136 to 224  $\mu\text{g.g}^{-1}$ ) (Costa et al., 2010; Freitas et al., 2017; Silva et al., 2009). When comparing the levels of tocopherol in buriti oil with that of soybean oil (1,170  $\mu\text{g.g}^{-1}$ ), recognized for its high contents of vitamin E, it's possible to confirm they are very close (Matthaus & Ozcan, 2014). Tocopherol can have a cardioprotective action by decreasing the infiltration of neutrophils into cardiac tissue and improving cardiac output and stroke volume (Wallert et al., 2019). In addition, this vitamin may have an important action in patients with colitis, since it can mitigate bleeding, improve the composition of bacterial flora, and protect the integrity of the intestinal wall (Liu, Nakatsu et al., 2021). Furthermore, tocopherol presents a systemic anti-inflammatory action, reduction of reactive oxygen species and lipid peroxidation markers (Minter et al., 2020; Wallert et al., 2019).

In addition, buriti pulp has considerable levels of phytosterols (183.0 to 265.0 mg.100  $\text{g}^{-1}$ ), mainly sitosterol ( $154.50 \pm 9.19$  mg.100  $\text{g}^{-1}$ ), but were also found stigmasterol ( $38.50 \pm 4.95$  mg.100  $\text{g}^{-1}$ ), campesterol ( $16.00 \pm 0.00$  mg.100  $\text{g}^{-1}$ ), brassicasterol ( $2.50 \pm 2.12$  mg.100  $\text{g}^{-1}$ ), and D5-avenasterol + D7-stigmasterol ( $3.50 \pm 2.12$  mg.100  $\text{g}^{-1}$ ) (Costa et al., 2010). These contents are higher than those reported for other Brazilian products, such as genipap pulp (*Genipa americana*; 216.0 mg.100  $\text{g}^{-1}$ ), red açaí pulp (*Euterpe oleracea*; 111.0 mg.100  $\text{g}^{-1}$ ), and Brazil nut (*Bertholletia excelsa*; 47.0-148.0 mg.100  $\text{g}^{-1}$ ) and for traditional products like peas (242 mg.100  $\text{g}^{-1}$ ), sesame (203 mg.100  $\text{g}^{-1}$ ), lentils (158 mg.100  $\text{g}^{-1}$ ), peanut (172 mg.100  $\text{g}^{-1}$ ), macadamia (161 mg.100  $\text{g}^{-1}$ ), and hazelnut (110 mg.100  $\text{g}^{-1}$ ) (Maguire et al., 2004; Ryan et al. 2007).

Phytosterols are molecules found in vegetables whose structure is like cholesterol. In most foods, sitosterol is the compound found in the highest concentrations, followed by campesterol and stigmasterol. Approximately 90% of these compounds are excreted in the faeces. In human serum, levels of sitosterol and campesterol are only 0.1-0.14% of the cholesterol concentration. Some studies describe that adequate consumption of these compounds may be related to lower LDL-c levels in human blood, in addition to reducing the risk of developing cardiovascular disease and preventing the development of cancer (Richard & Ostlund, 2002; Woyengo et al., 2009).

### *3.4. Bioactive compounds*

#### *3.4.1. Carotenoids*

Carotenoids are tetraterpenes with conjugated double bonds, which can be classified into carotenes and xanthophylls. Carotenes are hydrocarbons, while xanthophylls have hydroxy, carbonyl, aldehyde, carboxylic, epoxide, and furanoxide functional groups, thus being able to form esters of fatty acids, glycosides, sulfates, and protein complexes. These compounds can be found in photosynthetic bacteria and some species of plants, animals, algae, and fungi (Maoka, 2019). Among the more than 800 compounds identified in the scientific literature, approximately 50 of them have at least one unsubstituted  $\beta$ -ion ring, with a polyenic side chain, which, through enzymatic cleavage, can be converted into retinols, being called provitamin A (Maoka, 2019; Tanumihardjo et al., 2016; Yahia et al., 2018).

In the blood and some human organs, such as liver, ovaries, skin, prostate, testicles, and adrenal gland, 20 types of carotenoids can be found, of these,  $\beta$ -carotene,  $\alpha$ -carotene, lycopene,  $\beta$ -cryptoxanthin, lutein, and zeaxanthin. However, epoxy carotenoids are degraded because of high stomach acidity and are not absorbed, like antheraxanthin, neoxanthin, lutein epoxy, and violaxanthin (Maoka, 2019).

Deficiency of provitamin A carotenoids, as well as macular carotenoids (lutein, zeaxanthin, meso-zeaxanthin and their metabolites), can cause a spectrum of ocular derangements that manifest in nightblindness and macular degeneration caused by photo-oxidative damage. These problems are usually corrected with the adequate consumption of foods rich in these compounds (Arunkumar et al., 2020; Tanumihardjo et al., 2016).

The total content of carotenoids in buriti pulp varies from 349.9 to 632.2  $\mu\text{g.g}^{-1}$  according to the origin of the fruits, when they undergo environmental, climatic and soil

changes (Cândido et al., 2015; Nascimento-Silva et al., 2020). Other factors that may influence the concentration of carotenoids in fruits are the maturation stage and the storage conditions, which show an upward curve over time (Milanez et al., 2018).

Few studies were found that describe the profile of carotenoids in buriti pulp. The first study identified in the scientific literature was published in 1994, which carried out the extraction of the compounds manually, in grail and pistil with cold acetone and, later, transferred them to petroleum ether through liquid-liquid partition. The separation of the carotenoids was done in MgO:HyfloSupercel (1:2) column, and then each fraction provitamin A passed in a Ca(OH)<sub>2</sub> column (Godoy & Rodriguez-Amaya, 1994). The most recent studies used the same methodology for extracting the compounds, however, the separation was performed on HPLC-PDA-MS/MS (Cândido et al., 2015; Rosso & Mercadante, 2007).

Cândido et al. (2015) did not quantify the identified carotenoids, but they observed the presence of lutein, *cis*- $\gamma$ -caroteno, all-*trans*- $\gamma$ -caroteno, *cis*- $\delta$ -caroteno,  $\alpha$ -caroteno, all-*trans*- $\beta$ -caroteno, and 9-*cis*- $\beta$ -caroteno in *Mauritia flexuosa* pulp.

When analyzing the articles found in the scientific literature (Table 4), it is possible to conclude that the most recent study did not identify some compounds previously reported ( $\alpha$ -carotene and  $\beta$ -zeacarotene) in *Mauritia vinifera* pulp, however they described sixteen new carotenoids, mainly  $\gamma$ -carotene,  $\delta$ -carotene,  $\zeta$ -carotene, phytoene,  $\alpha$ -cryptoxanthin,  $\beta$ -cryptoxanthin and lutein. In addition, the most recent study showed much higher concentrations of *cis*- $\beta$ -carotene, but lower  $\alpha$ -carotene. The difference between the separation methods used in each of the studies has caused these divergences. According to Godoy & Rodriguez-Amaya (1994), his study group observed that the use of a Ca(OH)<sub>2</sub> column can lead to a 4% reduction in the levels of *trans*- $\beta$ -carotene and 6% in the levels of all-*trans*- $\beta$ -cryptoxanthin, and may thus also interfere with the concentration of other compounds. Considering this information, we proposed a pathway for the biosynthesis of carotenoids in buriti pulp (Fig. 2).

Both studies report considerable contents of carotenoids (490.8 to 513.87  $\mu\text{g.g}^{-1}$ ), mainly all-*trans*- $\beta$ -carotene, which ranged from 359.8 to 372.3  $\mu\text{g.g}^{-1}$ , representing approximately 70% of total content in the pulp (Godoy & Rodriguez-Amaya, 1994; Rosso & Mercadante, 2007). These levels are considered very high, according to the scale proposed by Britton & Khachik (2009) (low: 0-1  $\mu\text{g.g}^{-1}$ ; moderate: 1-5  $\mu\text{g.g}^{-1}$ ; high: 5-20  $\mu\text{g.g}^{-1}$ ; very high: >20  $\mu\text{g.g}^{-1}$ ). Besides, buriti has  $\beta$ -carotene contents higher than those in fruits known for high levels of carotenoids, such as acerola (*Malpighia glabra* or *M.*

*punicifolia*; 3.4 to 38.0 µg.g<sup>-1</sup>), mango (*Mangifera indica* L., 2.5 to 18.0 µg.g<sup>-1</sup>), orange (*Citrus sinensis*, 0.1 to 0.6 µg.g<sup>-1</sup>), papaya (*Carica papaya*; 1.2 to 7.5 µg.g<sup>-1</sup>), squash (*Cucurbita moschata*; 16.0 to 47.0 µg.g<sup>-1</sup>), and pumpkin (*Cucurbita maxima*; 15.0 to 21.0 µg.g<sup>-1</sup>) (Rodriguez-Amaya et al., 2008).

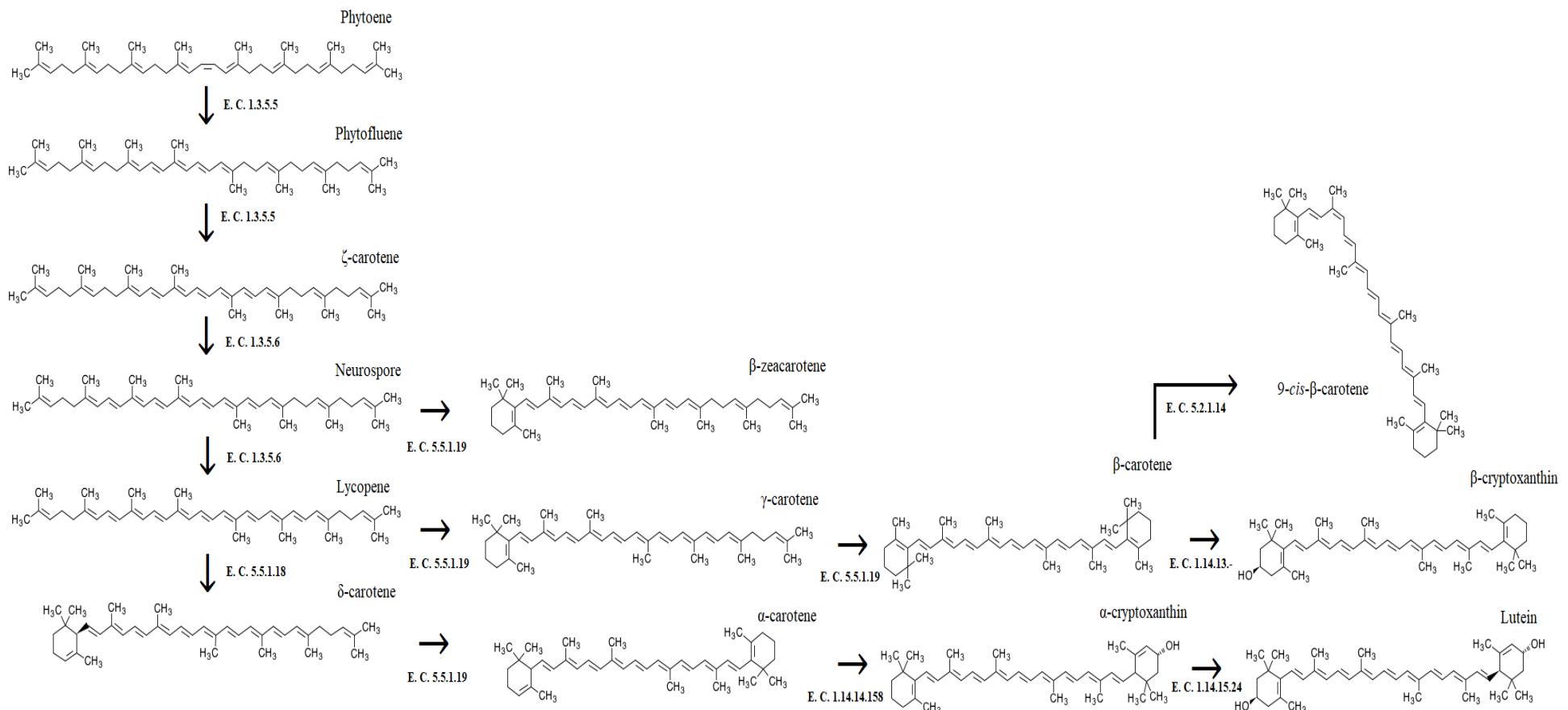
Regarding the vitamin A value of buriti (Table 4), it should be noted that this fruit has extremely relevant levels, since the Institute of Medicine, Food and Nutrition Board (IOM, 2001) recommends the daily consumption of 900 µg retinol activity equivalent (RAE) for men and 700 µg RAE for women.

Therefore, can be emphasized that buriti is a significant source of carotenoids, once they only contain compounds absorbed by the human body and play important biological functions in the various organs where they are found. Thus, further researches are needed to confirm the carotenoid profile in this fruit. In addition, studies describing the bioaccessibility and bioavailability of these carotenoids in buriti pulp are suggested.

**Table 4.** Carotenoid profile<sup>1</sup> (µg.g<sup>-1</sup>) and vitamin A value (RE.100 g<sup>-1</sup>) of buriti (*Mauritia vinifera*).

Carotenoids	Godoy & Rodriguez-Amaya (1994)	Rosso & Mercadante (2007)
phytoene	-	0.34
all-trans-ζ-carotene	-	0.08
all-trans-β-zeacarotene	5.4 ± 1.4	-
all-trans-γ-carotene	36.8 ± 4.5	14.76
cis-γ-carotene 2	-	2.33
cis-γ-carotene 3	-	9.88
all-trans-β-carotene	359.8 ± 32.5	372.32
9-cis-β-carotene	1.0 ± 0.5	18.57
13-cis-β-carotene	4.2 ± 2.4	59.23
15-cis-β-carotene	-	8.87
di-cis-β-carotene 2	-	0.11
5,6-epoxy-β-carotene	-	0.41
5,8-epoxy-β-carotene	-	7.44
5,6-epoxy-β-	-	0.10
cryptoxanthin		
all-trans-δ-carotene	-	2.09
cis-δ-carotene 1	-	5.46
cis-δ-carotene 2	-	3.67
cis-δ-carotene 3	-	2.42
all-trans-α-carotene	80.1 ± 9.0	3.23
13-cis-α-carotene	1.5 ± 1.4	-
all-trans-α-ryptoxanthin	-	1.28
di-cis-α-carotene	-	1.25
all-trans-lutein	-	0.03
Total carotenoids	490.8	513.87
Vitamin A value	6992 ± 462	7280

<sup>1</sup>Values are presented as mean ± standard deviation



**Fig. 2.** Proposed pathway for carotenoid biosynthesis in buriti pulp, based on the compounds identified in the literature (shown in Table 4), data available in the KEGG (Kyoto Encyclopedia of Genes and Genomes) database of carotenoid biosynthesis (<https://www.genome.jp/kegg/pathway.html>). Enzymes: E. C. 1.3.5.5 = phytoene desaturase; E. C. 1.3.5.6 =  $\zeta$ -carotene desaturase; E. C. 5.5.1.18 = lycopene  $\delta$ -cyclase; E. C. 5.5.1.19 = lycopene  $\beta$ -cyclase; E. C. 5.2.1.14 =  $\beta$ -carotene isomerase; E. C. 1.14.13.- =  $\beta$ -carotene hydroxylase; E. C. 1.14.14.158 = carotenoid  $\delta$ -hydroxylase; E. C. 1.14.15.24 =  $\beta$ -carotene 3-hydroxylase.

### *3.4.2. Phenolic compounds*

Phenolic compounds are molecules that have one or more hydroxyl groups linked to an aromatic ring (polyphenol), being classified according to the number of carbons in the molecule. They are found in plant tissues as esters or glycosides. One of the most discussed aspects about these compounds is their oxidation, which can cause changes in the color of plant tissue, such as when cutting fruits, or the formation of toxic metabolites for bacteria or animals, in order to protect the plant by inhibiting proliferation of pathogens (Marchiosi et al., 2020; Vermerris & Nicholson, 2006).

Some polyphenols have been used as antioxidants, because of the fact that they have an aromatic ring. These compounds easily self-oxidize when exposed to sunlight or oxygen, which leads to the abstraction of a proton and generates a radical, which can later react with other radicals to form dimers. Besides, oxidation can occur in consequence of presence of reactive oxygen species or enzymatic oxidation, because of the action of oxido-reductases that use oxygen as an acceptor, peroxidases and monophenol monooxygenase (Vermerris & Nicholson, 2006).

The antioxidant action of polyphenols has been associated with several benefits to the human body, such as its application in neurodegenerative diseases, cancer, cardiovascular diseases, metabolic disorders and autoimmune diseases. Moreover, these compounds have been applied in food science as coloring, flavoring, nutraceuticals and even active packaging, and in the cosmetics industry such as sun protectors, antiaging agents, anti-inflammatory agents, and healing agents (Dias et al., 2020).

Knowledge about simpler, cheaper and faster forms of determination are extremely important for the scientific community. Among the optical detection methods, the most utilized is spectrophotometry, as it allows the differentiation of the polyphenol classes even though simple and reasonable cost, but they do not allow the identification of the compounds, unless they are coupled to the liquid separation by chromatography or capillary electrophoresis. Besides, the chromatographic methods that have been used in the quantification of polyphenols are unspecific for this purpose, despite having as a principle the determination of their structural groups. Among these, the Folin-Ciocalteu assay has been used, based on the reduction of the phosphorololframato-phosphomolybdate complex by phenolic compounds in a product of the blue reaction. The adoption of chemical sensors and biosensors that use nanomaterials has attracted the attention of researchers for the identification of these compounds, since they are

low cost, are more easily operated, save time and have shown good sensitivity and selectivity (Ge et al., 2020).

The total content of phenolic compounds in buriti pulp varies from 360.08 to 495.87 mg GAE.100 g<sup>-1</sup>, according to the region of origin (Cândido et al., 2015; Nascimento-Silva et al., 2020). Other factors can lead to variations in these compounds are the maturation stage and the solvent used in the extraction, since the aqueous extract being more effective than the ethanol (Milanez et al., 2018). This fruit has polyphenols levels close to that of other fruits known for their high levels of these compounds, such as blackberry (*Robus*; 226 mg GAE.100 g<sup>-1</sup>), raspberry (*Rubus idaeus*; 267 mg GAE.100 g<sup>-1</sup>), strawberry (*Fragaria*; 364 mg GAE.100 g<sup>-1</sup>), açaí (*Euterpe oleracea*; 454 mg GAE.100 g<sup>-1</sup>), fig (*Ficus carica*; 463 mg GAE.100 g<sup>-1</sup>), and acerola (*Malpighia glabra* or *M. punicifolia*; 1063 mg GAE.100 g<sup>-1</sup>) (Haminiuk et al., 2012).

**Table 5.**

Phenolic compounds of *M. flexuosa* pulp (μg.g<sup>-1</sup>, dry weight).

Compounds <sup>1</sup>	Bataglion et al. (2014)	Tauchen et al. (2016)
<i>Phenolic acids</i>		
<i>p</i> -Coumaric acid	277.74 ± 12.44	0.058 ± 0.01
Ferulic acid	184.66 ± 8.86	0.093 ± 0.03
Protocatechuic acid	2175.93 ± 18.01	-
Quinic acid	230.74 ± 11.29	-
Chlorogenic acid	1154.15 ± 9.69	10.35 ± 0.07
Caffeic acid	895.53 ± 4.80	0.054 ± 0.02
Gallic acid		0.062 ± 0.01
Salicylic acid		0.016 ± 0.00
Sinapic acid		0.347 ± 0.03
Syringic acid		0.049 ± 0.01
Vanillic acid		0.011 ± 0.02
<i>Flavonoids</i>		
Apigenin	102.48 ± 0.29	0.015 ± 0.00
Apigenin-7-glucoside	-	0.020 ± 0.00
(+)-Catechin	961.21 ± 2.68	-
(-)-Epicatechin	1109.93 ± 4.24	0.186 ± 0.07
Luteolin	1060.90 ± 6.95	0.055 ± 0.00
Luteolin-7-glucoside	-	0.054 ± 0.00
Myricetin	145.11 ± 5.15	-
Kaempferol	41.54 ± 4.47	-
Quercetin	83.27 ± 1.01	0.033 ± 0.00
Quercetin-3-arabinoside	-	0.028 ± 0.00
Naringenin	-	0.071 ± 0.00
Naringenin-7-glucoside	-	0.030 ± 0.00
Isoquercitrin	-	5.858 ± 0.08
Rutin	-	3.998 ± 0.11
Pterostilbene	-	0.058 ± 0.00
Resveratrol	-	0.065 ± 0.00

<sup>1</sup>Values are presented as mean ± standard deviation.

Few studies were found that described phenolic compounds in buriti, and only two quantified these compounds. The first study identified 13 polyphenols in extracts from different parts of the plant (stem, leaf and fruit) (Koolen et al., 2013). In this research it was reported (+)-catechin, caffeic acid hexoside, chlorogenic acid, quercetin, myricetin, vitexin, scoparin, rutin, cyanidin-3-rutinoside, & cyanidin-3-glucoside in the extract produced with peel and pulp.

Gomes et al. (2016) performed electrochemical detection of flavonoids in extracts of several fruits, among which, find peonidin-3-O-glucoside and peonidin in buriti extracts. In a more recent study, Abreu-Naranjo et al. (2020) identified quercetin-dihexoside, myricetin glucuronide, methylmyricetin-O-glucuronide, quercetin-O-rutinoside, quercetin-O-glucoside, quercetin-3-O-glucuronide, kaempferol-3-O-glucoside, kaempferol 3-O-glucuronide, naringenin hexoside, luteolin-O-deoxyhexoside, naringenin, quercetin, cyanidin-3-rutinoside, and cyanidin-3-glucoside in fruits (peel and pulp) of buriti. The only studies that carried out the quantification of phenolic compounds in buriti pulp is detailed in Table 5. Large variations were found between the results of the studies, probably because of the difference in the methods of preparation and extraction of compounds, since Tauchen et al. (2016) carried out the extraction at 130 °C with Soxhlet equipment.

Protocatechuic acid (PCA), one of the compounds found in higher levels in buriti pulp, has several pharmacological effects. For example, its therapeutic potential in neurodegenerative diseases such as Alzheimer's disease and Parkinson's disease. The described mechanism of action involves the prevention of neurotoxicity, inhibition of glutamate release, generation of ROS, control of inflammation by counteraction of inflammatory mediators and enzymes, and inhibition of NF-κB activation and its translocation to the nucleus (Krzysztoforska et al., 2017). Other studies report that PCA presents antiatherogenic and antiatherosclerosis properties by reducing NF-κB activation and inhibiting monocyte infiltration and adhesion molecules; anticoagulatory effects by lowering inflammatory cytokines; insulin-like activity in adipocytes by increasing PPAR $\gamma$  activation; attenuated diabetic conditions by lowering plasma glucose, increasing insulin, and lowering triglyceride levels; antiapoptotic activities via attenuated changes of mitochondrial membrane permeability and decreased oxidative stress damage; and had a cell-protective effect via its antioxidant and scavenging activity (Semaming et al. 2015).

Moreover, flavonoids have been described as strong candidates to treat various types of cancer via modulation of the apoptotic pathway, reduced cell growth and

proliferation, increased cell death and decreased metastatic potential (Abotaleb et al., 2019). Flavonoids act as antioxidants under normal conditions and are strong pro-oxidants in tumor cells, disrupting pro-inflammatory signaling pathways (Kopustinskiene, Jakstas, Savickas, & Bernatoniene, 2020). Other functions of these compounds have been reported, among them the anti-oxidative activity, free radical scavenging capacity, cardioprotective, antidiabetic, anti-inflammatory, anti-allergic, and potential antiviral activities (Karak, 2019).

In this way, the buriti stands out for its diversity and abundance of phenolic acids and flavonoids. However, no studies were found that analyzed the bioavailability of these compounds in this fruit, so we are not sure of the amounts available for absorption in the human body. Several factors can influence this bioavailability. Among these factors, the proximate composition of the food matrix stands out, mainly the content of lipids, which can positively or negatively influence the availability of polyphenols (Dias et al., 2020).

#### **4. Health benefits**

Because of the profile and considerable contents of bioactive compounds in buriti pulp, some experimental studies were conducted to correlate these compounds with some biological effects *in vitro* and *in vivo* (Table 6).

Buriti pulp can be a useful complement to the treatment of intestinal inflammation, since its supplementation in rats prevented the damage caused by neutrophil-derived oxidants by reducing the levels of alkaline enzymes phosphatase and myeloperoxidase (neutrophils infiltration markers), which they have high toxicity and modulate oxidative stress by decreasing glutathione levels. In addition, buriti modulated the inflammatory process by reducing the pro-inflammatory cytokines (IL-6, IL-1 $\beta$  and TNF- $\alpha$ ), whose production is associated with oxidative stress, and also increased the mucin, which promotes the recovery of intestinal cell architecture (Curimbaba et al., 2020).

Modulation of oxidative stress in hippocampal tissue, caused by supplementation of *M. flexuosa* pulp, can ease symptoms caused by mercury poisoning by preventing neurotoxicity, the memory acquisition impairment, and the lipid peroxidation in the brain. Although, the mechanism involved in the memory impairment induced by oxidative stress in the hippocampal tissue is not fully understood (Leão et al., 2017).

**Table 6.**

Summary of experimental studies investigating the effects of buriti on health.

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
<i>M. flexuosa</i> pulp	Male Wistar rats (8 weeks old, 180-220 g)	35 days (33 days prior to TNBS induction of intestinal inflammation and 2 days thereafter); 5 groups (n = 7): (1 e 2) control - 0.25 mL saline (0.9% NaCl, pH 7.0) and the standardized rodent; (3) 10% enriched-feed of açaí berry; (4) 10% enriched-feed of buriti pulp; (5) 10% enriched-feed of cupuaçu pulp.	<p><i>Intestinal inflammation</i></p> <p>All diets did not produce a significant effect on the extension of lesions. However, the diet enriched with buriti pulp reduced the damage score, and the diet with cupuaçu decreased diarrhea and adherence to adjacent organs.</p> <p>The intervention groups had moderate edema in their submucosa, less inflammatory infiltration and ulceration, straighter tubular glands with normal crypts, and more goblet cells when compared with the control groups.</p> <p>Dietary supplementation with açaí and buriti increases the activity of alkaline phosphatase and myeloperoxidase, as well as reducing glutathione depletion, and the levels of IL-6, IL-1<math>\beta</math> and TNF-<math>\alpha</math>.</p>	Curimbaba et al. (2020)
<i>M. flexuosa</i> pulp	Male Wistar (3 months old, 250-280 g)	<p>7 days; 2 groups (n = 14): (1) control – commercial diet; (2) commercial diet:fruit pulp (1:1 g.g<math>^{-1}</math>).</p> <p>After diet period, each group was subdivided into two (n = 7): an exposed group (5 mg/kg/day MeHg by gavage during 3 consecutive days) and an unexposed group (saline solution).</p> <p>This step was followed by 5 days of acclimatization before behavioral or biochemical analysis.</p>	<p><i>Memory acquisition</i></p> <p>Animals intoxicated with MeHg and feed with <i>M. flexuosa</i>-enriched ration did not show lack of memory acquisition from avoidance 1 test. However no difference was observed in avoidance 2 test when compared with control.</p> <p><i>Lipid peroxidation in hippocampus</i></p> <p>The animals intoxicated with MeHg and feed with <i>M. flexuosa</i>-enriched ration did not show increased hippocampal TBARs levels when compared with control. blocking the oxidative stress induced by MeHg in the brain hippocampus.</p>	Leão et al. (2017)
<i>M. flexuosa</i> pulp oil	Male Wistar rats ( $\pm$ 21 days)	28 days; 3 groups (n = 10): (1) CG - 7 g soybean oil.100 g $^{-1}$ diet; (2) CBO - 7 g crude buriti oil.100 g $^{-1}$ diet; (3) RBO - 7 g refined buriti oil.100 g $^{-1}$ diet	<i>Vitamin A and E status</i>	Aquino et al. (2015a)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
<i>M. flexuosa</i> pulp oil	Male Wistar rats ( $\pm$ 21 days old, $\pm$ 60 g)	<p>All the groups received: 2.4 mg of <math>\beta</math>-carotene/kg of diet and 49.95 mg of <math>\alpha</math>-tocopherol/kg of diet.</p> <p>17 days; 4 groups (n = 7): (1) CS – saline + soybean oil; (2) CB – saline + AIN 93M diet + Buriti oil; (3) ES – iron II sulfate + soybean oil; (4) EB – iron II sulfate + Buriti oil. All of them also received daily gavage and AIN 93M diet.</p> <p>Oxidative stress was induced by iron II sulfate (2 mL.100 g<sup>-1</sup> body weight) for experimental groups.</p> <p>After the experimental period and a 12h fasting period, the animals were anesthetized and blood was collected by direct cardiac puncture for the collection of 4 mL from each animal.</p>	<p>The liver <math>\alpha</math>-tocopherol concentration in the CBO group (<math>36.68 \pm 1.19 \mu\text{g.g}^{-1}</math>) was higher than the RBO group (<math>24.7 \pm 1.79 \mu\text{g.g}^{-1}</math>), and the CG group (<math>12.33 \pm 1.5 \mu\text{g.g}^{-1}</math>).</p> <p><i>Cholesterol profile</i></p> <p>The animals that received RBO had the lowest levels (52.25 mg.dL<sup>-1</sup>) of total cholesterol and LDL-c (30.84 mg.dL<sup>-1</sup>) in comparison with the other groups (CBO: TC=131.51 mg.dL<sup>-1</sup>, LDL-c=87.49 mg.dL<sup>-1</sup>; CG: TC=96.83 mg.dL<sup>-1</sup>, LDL-c=57.88 mg.dL<sup>-1</sup>). The CBO group had the biggest TC values, TC/HDL-c and LDL-c ratios.</p> <p><i>Cholesterol profile</i></p> <p>No significant weight change was observed between groups.</p> <p>The animals in the CS group (2.06 g) had a heavier liver than those in the CB group (1.56 g).</p> <p>There was no difference among groups for total cholesterol, HDL-C and LDL-C. The serum triglyceride levels were lower in the control group (CS = 41.2 mg.dL<sup>-1</sup>), followed by the groups that received buriti oil (65.0-68.6 mg.dL<sup>-1</sup>). However, animals in the ES group had the highest levels (95.2 mg.dL<sup>-1</sup>).</p>	Aquino et al. (2015b)
<i>M. flexuosa</i> pulp oil	36 Wistar neonate rats obtained from primiparous rats were mated at 120 days of age	<p>3 groups: (1) CG - 7 g soybean oil.100 g<sup>-1</sup> diet; (2) CBO - 7 g crude buriti oil.100 g<sup>-1</sup> diet; (3) RBO - 7 g refined buriti oil.100 g<sup>-1</sup> diet.</p> <p>Animals received control and experimental diets during pregnancy and lactation.</p> <p>Reflexes were daily assessed from the second day to the twenty-first postnatal day. At the end of lactation, animals were anesthetized,</p>	<p><i>Somatic growth</i></p> <p>The weight gain of newborns was similar in all groups, but the groups that received buriti oil had higher values for tail length. However, animals from buriti oil groups showed delayed maturation of palm grasp reflex, righting reflex and cliff avoidance when compared with the control group.</p> <p>The animals from RBO group showed delayed eye opening and eruption of superior and inferior incisors in relation to the control</p>	Medeiros et al. (2015)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
<i>M. flexuosa</i> pulp oil	Male C57BL/6 mice	<p>blood was collected by cardiac puncture and liver was removed for retinol assessment.</p> <p>12 weeks; 4 groups (n = 12): (1) lean-C – olive oil by daily gavage; (2) obese-C – olive oil by daily gavage; (3) 50 mg-BPO group – obese fed with 50 mg.Kg<sup>-1</sup> of buriti pulp oil; (4) 100 mg-BPO group – obese fed with 100 mg.Kg<sup>-1</sup> of buriti pulp oil.</p>	<p>group and anticipation in the auditory canal opening in relation to the CBO group. CBO group showed delayed eruption of superior incisors compared with the control group.</p> <p>The highest serum and liver retinol concentrations were verified in animals fed with butiti oil.</p> <p><i>Metabolic effect</i></p> <p>After the end of the trial, the groups treated with buriti pulp oil had the greatest weight gain, especially the 50 mg-BPO group.</p> <p>Seric glucose, total cholesterol, uric acid and ALT were higher in the 100 mg-BPO group when compared to the Lean-C group, and triglycerides were higher than all other groups. Also, 50 mg-BPO showed a higher level of uric acid than Lean-C and Obese-C groups.</p> <p>The 50mg-BPO group had adipocytes with an area statistically equal to the Obese-C group, whereas the 100 mg group presented the lowest adipocytes area.</p> <p>All groups showed an increase in fat deposits in the kidneys, but the only one that showed statistical difference compared to the others was the 100 mg-BPO group.</p> <p>Histological analysis of the liver showed that Obese-C and 100 mg-BPO group presented mild, diffuse and macrovesicular steatosis with a higher concentration. Also, the 50mg-BPO group presented a moderate median for diffuse and macrovesicular steatosis.</p> <p>There was no statistical difference in glutathione (GSH) and TBARS in high-fat groups.</p> <p>Blood glucose in the 50 mg-BPO group had lower glucose tolerance than other groups.</p>	Aydos et al. (2020)
<i>M. flexuosa</i> pulp oil	Human hepatocellular	liver	<i>Cytotoxicity assay</i>	Falcão et al. (2017)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
	carcinoma cell line (HepG2)	<p>96 well plates were inoculated with HepG2 cells. After incubation for 24 h, the adherent cells were washed with phosphate-buffered saline and then incubated for with EMEM containing different concentrations of oil emulsions (<math>0.5\text{-}4 \text{ mg.mL}^{-1}</math>). Positive control: untreated cells. Control: emulsified system without the sample.</p> <p>After removing the medium, cells were treated with MTT solution and PBS. Then, the plate was incubated at <math>37^\circ\text{C}</math> for 3 h.</p> <p><i>Antioxidant activity</i></p> <p>The cells were incubated in EMEM with FBS. Then, they were washed with PBS, treated with 3 mL of the samples (<math>0.5</math> and <math>1 \text{ mg.mL}^{-1}</math> of oil) and incubated. They were washed with PBS, scrapped and centrifuged. The pellet was re-suspended in <math>200 \mu\text{L}</math> of PBS and placed in the ultrasonic cold bath.</p>	<p>Lower concentrations of the samples (<math>0.5</math> and <math>1.0 \text{ mg.mL}^{-1}</math>) maintained cell viability around 100 %, and a significant decrease in cell viability was observed in treatments with <math>1\text{-}2 \text{ mg.mL}^{-1}</math> of oil emulsions. The decrease in the cell viability was maintained in all samples tested up to the highest concentration (<math>4 \text{ mg.mL}^{-1}</math>).</p> <p><i>Antioxidant activity</i></p> <p>The treatment with buriti oil (<math>0.5 \text{ mg.mL}^{-1}</math>) led to an increase in catalase activity in the HepG2 cells.</p>	
<i>M. flexuosa</i> pulp	Wistar rats (21 days old, $36 \pm 0.66 \text{ g}$ )	<p>60 days, 4 groups (<math>n=10</math>): (1) control males – standard feed; (2) control females – standard feed; (3) buriti males – buriti pulp-enriched feed; (4) buriti females – buriti pulp-enriched feed.</p> <p>After 60 days, the <i>in vivo</i> antioxidant activity was evaluated through the determination of the catalase activity and non-protein sulfhydryl (NPSH) groups in the liver and quantification of malondialdehyde (MDA) in the plasma and tissues.</p>	<p><i>Antioxidant activity</i></p> <p>Buriti pulp intake did not affect the activity of catalase in the liver, but the levels of NPSH groups in the male rats from the experimental group were higher, but the same was not observed for the females. There were no statistically significant alterations in the concentrations of MDA in the plasma, kidneys or liver, consequently, no significant alterations in lipid peroxidation were demonstrated.</p>	Romero et al. (2015)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
<i>M. flexuosa</i> pulp oil	Enteropathogenic E. coli (EPEC) by mononuclear phagocytes from human blood	Mononuclear phagocytes, buriti oil, and EPEC culture line EPEC-ATCC 25922 were incubated in a water bath for 30 min at 37 °C. The negative control used only mononuclear phagocytes and EPEC, while the positive control also used an immunostimulator, the lipopolysaccharide (LPS).	<i>Immunomodulatory effect</i> Buriti oil increasing the rate of phagocytosis of EPEC by mononuclear blood cells, causing a significant increase in microbicidal activity. Buriti oil did not present toxicity to human blood mononuclear phagocytes and that its viability indexes were higher than 95%.	Cruz et al. (2020)
<i>M. flexuosa</i> pulp oil	Bacterial species: <i>Staphylococcus aureus</i> , <i>Pseudomonas Aeruginosa</i> , and <i>Escherichia coli</i>  Multiresistant strains: <i>Escherichia coli</i> Ec 27 and <i>Staphylococcus aureus</i> Sa 358	Brain heart infusion broth (BHI) the 3.8% was used for bacterial growth (24 h, 35 ± 2 °C). A total of 100 µL of each dilution was distributed in 96-well plates with each oil ( <i>Orbignia speciosa</i> and <i>Mauritia flexuosa</i> ), achieving 5x10 <sup>5</sup> CFU.mL <sup>-1</sup> as final concentration of the inoculum.  The initial solution of each oil was performed using 10 mg of oil dissolved in 1 mL of dimethyl sulfoxide (DMSO) (10 mg.mL <sup>-1</sup> ). Several dilutions were made in distilled water to get a stock solution of 1024 µg.mL <sup>-1</sup> .  The modulating effect of oils on aminoglycoside antibiotics (amikacin, gentamicin and neomycin), was also evaluated.	<i>Antibacterial activity</i> For <i>M. flexuosa</i> fixed oil, the greatest inhibitory activity was for <i>S. aureus</i> Sa 358 (MIC 256 µg.mL <sup>-1</sup> ), and for all other strains the same MIC value (512 µg.mL <sup>-1</sup> ) was found. Buriti oil did not improve the effect of aminoglycoside antibiotics. The <i>Orbignia speciosa</i> oil demonstrated a significant reduction in MIC (minimal inhibitory concentration) values for amikacin against <i>S. aureus</i> Sa 358 and <i>P. aeruginosa</i> strains, and for the neomycin against strains of <i>S. aureus</i> Sa 358, <i>P. aeruginosa</i> and <i>E. coli</i> Ec 27.	Nobre et al. (2018)
<i>M. flexuosa</i> pulp	Bacterial species: <i>Bacillus cereus</i> , <i>Staphylococcus aureus</i> , <i>Escherichia</i>	The fractions were diluted in sterile distilled water and DMSO (1,024 mg.mL <sup>-1</sup> ). Serial dilutions were performed to obtain	<i>Antibacterial activity</i> The fractions caused synergistic and antagonistic effects in the antibiotics.	Nonato et al. (2018)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
	<i>coli</i> and <i>Salmonella choleraesuis</i>	concentrations ranging from 512 to 8 mg.mL <sup>-1</sup> .	The chloroform fraction exerted a synergistic effect in combination with gentamicin against <i>B. cereus</i> and <i>S. choleraesuis</i> , and in association of cefotaxime against <i>B. cereus</i> . On the other hand, the fraction exerted an antagonistic effect when combined with benzylpenicillin against <i>B. cereus</i> .	
	Yeast strains: <i>Candida albicans</i> , <i>Candida krusei</i> and <i>Candida tropicalis</i>	The modulating effect of the <i>M. flexuosa</i> was analyzed by combining them with aminoglycosides (amikacin and gentamicin), beta-lactams (benzylpenicillin and cefotaxime) and azoles (fluconazole and ketoconazole).	In association of amikacin or cefotaxime, the chloroform and the ethanol extracts showed a synergistic effect against <i>S. choleraesuis</i> . However, in combination with benzylpenicillin against <i>S. choleraesuis</i> only the ethyl acetate and ethanol extracts potentiated the action of the antibiotic.	
<i>M. flexuosa</i> pulp and fixed oil	Bacterial species: <i>Staphylococcus aureus</i> , <i>Bacillus cereus</i> , <i>Escherichia coli</i> , <i>Pseudomonas aeruginosa</i> , <i>Klebsiella pneumoniae</i> , <i>Shigella flexneri</i> , and <i>Proteus vulgaris</i>  Multiresistant strains: <i>S. aureus</i> SA-10 and <i>E. coli</i> EC-06	Eppendorfs were prepared with 100 µL of the inoculum and 900µL of the brain heart infusion culture medium in a concentration of 10%. Serial dilutions were performed.  The modulating effect of the <i>M. flexuosa</i> was analyzed by combining them with aminoglycosides (amikacin and gentamicin).	<i>Antifungal activity</i>  The fractions did not present significant effects, when associated to the drugs against <i>C. albicans</i> and <i>C. krusei</i> .  <i>Antibacterial activity</i>  High MIC values ( $\geq 1024 \mu\text{g.mL}^{-1}$ ) for all standard and multiresistant bacterial strains were reported. High values of MIC (512 $\mu\text{g.mL}^{-1}$ ) were observed for the fixed oil of the pulp extracted with hexane.  The synergic effects of the fixed oil in association with aminoglycoside antibiotics were described.	Pereira et al. (2018)
<i>M. flexuosa</i> pulp oil	Keratinocyte cell line HaCaT and the mouse embryonic fibroblast cell line 3T3	5 Emulsions: 2 O/W macroemulsions containing liquid crystals (29R and 51LC); 1 simple O/W emulsion (51S); 1 W/O/W multiple emulsion (37M); 1 O/W	<i>Photoprotective potential - topical use</i>  The formulations and the Buriti oil caused a small decrease in HaCaT cell viability when compared to the controls cells without product.	Zanatta et al. (2010)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
<i>M. flexuosa</i> pulp oil	Female Wistar rats ( <i>Rattus norvegicus albinus</i> ) (12 weeks old) – (120 ± 30 g).	<p>nanoemulsion (37N). Emulsions were diluted in DMEM with 10% FBS at a final concentration of 125 mg/ml. The buriti oil was diluted in DMEM with 10% FBS, after previous solubilization in DMSO, at a final concentration of 100 µl.ml<sup>-1</sup>.</p> <p>Cell treatment: prior and after the irradiation.</p> <p>When culture cells reached confluence, the medium was removed from the wells corresponding to pre-treatment condition. These cells were treated with 100 µl of the emulsions with and without active ingredient (1% of α-tocopherol or panthenol) for 15 min at 37 °C, 5% CO<sub>2</sub>.</p> <p>4 groups (n = 12): (1) control group - distilled water; (2) M: <i>Astrocaryum murumuru</i> butter; (3) MB1: 1% <i>Mauritia flexuosa</i> oil; (4) MB15: 15% <i>M. flexuosa</i> oil.</p> <p>All animals were subjected to a 1 cm<sup>2</sup> dorsal injury.</p> <p>Treated groups received 0.1 g of the formulations as daily topical administration until the day of euthanasia.</p> <p>On postoperative days 3, 7, 14, and 21, three animals from each group were euthanized with an anesthetic overdose.</p>	<p>The Buriti oil emulsions, produced with Steareth-2 associated to surfactant (Ceteareth-5 or Ceteareth-20), containing or not α-tocopherol, were not capable to avoid or reduce the damages caused by UVA and UVB radiation.</p> <p>The Buriti oil emulsions could be considered potential vehicles to transport antioxidants precursors and also be used as adjuvant in sun protection formulations and especially in after sun formulations.</p> <p><i>Healing activity - topical use</i></p> <p>Both formulations with buriti oil showed improvement in the wound after 3 days. Both endothelial cell angiogenesis and collagen deposition in the wound area can be induced by MB1 and MB15 herbal formulations. However, the best results were presented by MB15, which stood out from other treatments in all phases of the healing process.</p> <p>The <i>in silico</i> prediction of skin sensitization showed that none of the identified compounds had any potential skin toxicity for humans.</p>	Silva et al. (2021)
<i>M. flexuosa</i> pulp oil	Male Wistar rats ( <i>Rattus norvegicus albinus</i> ) - (250-300 g)	<p>3 groups (n = 12): (1) control group; (2) Myositis induced; (3) myositis induced and treated with the oil extraction of <i>M. flexuosa</i> L.</p> <p>Each group was subdivided into 2 subgroups (n=6) according to the observation period/euthanasia of 7 and 14 days.</p>	<p><i>Healing activity - topical use</i></p> <p>All groups had myositis after 7 and 14 days, but groups treated with buriti pulp oil showed a significant reduction in neutrophil concentration, and better effect on muscle tissue repair in both times of the experiment.</p>	Barbosa et al. (2017)

Supplement	Animals / Cell culture / Microorganisms	Study design	Biological effects	References
<i>M. flexuosa</i> pulp oil	Male Wistar rats (60 days old, 120 g)	21 days; 2 groups (n = 20): (1) rats with skin injury treated with buriti oil cream (10%); (2) rats with skin injury treated with regular cream.	<p><i>Healing activity - topical use</i></p> <p>On the third postoperative day, the wounds of animals treated with buriti oil showed mild hyperemia and an initial stage of crust formation, while the other group presented lesions with marked hyperemia and swollen edges.</p> <p>On the seventh postoperative day, the wounds treated with buriti oil had a thin crust flush with the skin and no evidence of inflammation. The same was not observed in the control group, whose wounds remained with a macroscopic appearance similar to that observed on the third day, with thick crust and presence of purulent exudate in three animals.</p> <p>After 14 days, the wounds treated with buriti oil were healed, demonstrating a significant reduction in macrophage counts, as well as the presence of no blood vessels. While the wounds of the animals in the control group had not yet completed the healing process.</p>	Batista et al. (2012)

Studies (Table 6) indicate that the oil produced from buriti pulp can be used for microbicidal purposes, since its high levels of tocophenols and carotenoids can modulate the oxidative metabolism of neutrophils and increase phagocytosis and macrophages levels (Cruz et al., 2020). The *M. flexuosa* fixed oil can reduce the activity of some bacterial species and multiresistant strains, mainly Gram-positive bacteria, which can be justified by the association of the fatty acids components of these oils with the hydrophobic portion of the bacterial cells membranes, which would increase the permeability of these structures to the entry of antibiotics (Nobre et al., 2018). Moreover, the buriti oil can potentiate the effect of some antifungals and antibiotics (Table 6).

However, not all studies showed the desired results. Medeiros et al. (2015), for example, described that supplementation with buriti oil, during gestation and lactation of rats, can negatively affect somatic growth and maturation of some reflexes (palm grip, righting reflex and evasion of the cliff) of newborn rats, despite having observed a significant increase in serum and liver retinol levels. The authors associated the fact with the fatty acid profile of the oil in question, since the same was not described for soybean oil. In addition, Aquino et al. (2015a) and Aquino et al. (2015b) observed that rats that received crude buriti oil had higher serum triglyceride levels than those that received soy oil, despite having higher levels of vitamin A and vitamin E in plasma and liver. Furthermore, Aydos et al. (2020) reported that obese mice treated with buriti oil added bigger weight gain, higher fat deposition in the kidneys, and higher levels of blood glucose, total cholesterol, uric acid, and liver enzymes after 12 weeks of treatment, when compared to the control group fed with olive oil.

Zanatta et al. (2010) also got results that differed from what was desired when they observed that the application of an emulsion containing buriti oil could not contain the damage caused by UVA and UVB rays. As previously described in this review, buriti is rich in bioactive compounds, mainly carotenoids, whose photoprotective action is already well described in the literature. However, according to Zanatta et al. (2010) the surfactant used in the analysis caused the initial oxidative damage and reducing cell viability, even before the cells were exposed to radiation. Furthermore, the combination of antioxidants added to the emulsion, besides those already present in buriti oil, may have exerted a pro-oxidant effect on keratinocyte cells, contributing to undesirable phototoxic effects.

On the other hand, studies that evaluated the curative and healing power of the topical use of oil extracted from buriti pulp observed an improvement in the lesion after three days and an initial stage of crust formation and tissue repair, as well as a reduction in signs of

inflammation and neutrophil concentration (Barbosa et al., 2017, Batista et al., 2012, Silva et al., 2021).

These findings suggest that buriti pulp has the potential to be used as a modulator of the immune and oxidative system, in addition to being an alternative for inflammatory diseases and for mercury poisoning. However, few trials were found, so further studies in animals and, mainly, in humans are suggested, in order to describe these and other applications of buriti in the body, as well as to specify its mechanism of action.

## 5. Conclusion and future directions

The present review highlighted the importance of the fruit of *Mauritia flexuosa*, describing its nutritional value and its effect on human health. The fruit has a high nutritional value and can be considered an excellent source of magnesium, since 100 g of the fruit can offer between 204 and 565% of the RDA. Compared to other fruits, there is a high level of lipids, which is reflected in the significant concentrations of oleic and palmitic acids, which are the main fatty acids found in the human brain, and in the structure and function of the uterus. In addition, we must emphasize the content and profile of tocopherols, which are like soybean oil, recognized for its Vitamin E content. Buriti pulp can provide phytosterols at representative levels, and their consumption can prevent the risk of development of non-communicable chronic diseases.

As expected, the contents of carotenoids, especially  $\beta$ -carotene, in buriti pulp are high, however few studies were found regarding the profile of these compounds. It is important to emphasize the need for more studies, since its content stands out over other fruits. The same was observed for the content and profile of phenolic compounds.

The need for studies reporting the bioavailability of these compounds in buriti pulp is highlighted, since knowledge about the bioavailable fraction is even more important than just describing the profile of compounds, as they may not be available for target tissues.

Supplementation with pulp or oil produced from buriti pulp proved to be an alternative in modulating the immune and oxidative system. Thus, studies suggest that this fruit can be used in the prevention of inflammatory diseases, as a microbial agent and, when applied topically, it can have a healing action. This study was a pioneer in suggesting a pathway for the biosynthesis of carotenoids in buriti pulp.

Likewise, research aimed at elucidating the biological properties, as well as the mechanism of action of bioactive compounds found in plants, should be carried out, as they will certainly contribute to the establishment of safe dosages and to increase interest in the discovery of new molecules of biological interest.

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### Author disclosure statement

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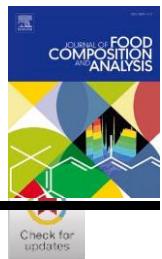
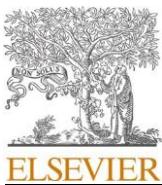
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## **Artigo 2**

### **Jambolan (*Syzygium cumini* (L.) Skeels): A review on its nutrients, bioactive compounds and health benefits**

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## Jambolan (*Syzygium cumini* (L.) Skeels): A review on its nutrients, bioactive compounds and health benefits

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### ABSTRACT

Jambolan is a colored fruit that varies from yellowish-green to black, from the *Myrtaceae* family and the *Syzygiaeae* tribe. This review proposes a general view regarding the nutritional and health benefits aspects, and the health benefits of the main components of jambolan fruit. The fruit has attracted the attention of the food industry because of its color and high sugar content. Phytochemicals levels stood out, especially the levels of anthocyanins, which tend to increase from 28.5 to 1318.4 mg/100 g during ripening. Studies report the presence of delphinidin, cyanidin, petunidin, peonidin and malvidin in the pulp and peel of *Syzygium cumini* (L.) Skeels. There were reports of the presence of lutein, zeaxanthin, β-carotene and β-cryptoxanthin in the fruit. This work was the first to propose a possible pathway for carotenoid biosynthesis in *S. cumini* with the available data. Additionally, several studies have associated the consumption of *S. cumini* with antidiabetic, hypolipidemic, antioxidant, and hepatoprotective effects.

## 1. Introduction

*Syzygium cumini* (L.) Skeels, a fruit from the *Myrtaceae* family and the *Syzygiaeae* tribe, is originally from Asia, being usually found in India, Bangladesh, Burma, Nepal, Pakistan, Sri Lanka, Indonesia, Malaysia, Thailand and the Philippines, adapting well to tropical and subtropical climates, and dispersing across several countries in Africa and Latin America (Biffin et al., 2010; Sabino et al., 2018).

Because of this great geographical dispersion, several scientific names for the fruit arose, including *Eugenia jambolana* Lam., *Myrtus cumini* Linn., *Syzygium jambolana* DC., *Syzygium jambolanum* (Lam.) DC., *Eugenia djouant* Perr., *Calyptranthes jambolana* Willd., *Eugenia cumini* (Linn.) Druce., and *Eugenia caryophyllifolia* Lam. In addition, it has several popular names, such as jambolan, jamun, jamblon, jambolana, jamoon, black plum, blackberry, jamelão, jalaão, azeitona-roxa, murta, jambuí, oliva, oliveira, java plum, portuguese plum, malabar plum, purple plum, damson plum, jaman, jambu, jambool, jambhool, jame-long, jamblang, jiwat, salam, jambeiro, jambul and java plum (Mesa,

2012; Sabino et al., 2018).

The *S. cumini* tree is broadleaf species with a densely foliated crown, reaching a height of 15 m. The harvest of the fruit begins after 9–10 years of planting. The fruit shows maturity after flowering, that can occur in masses in a few days or steadily for up to 3 months. Bee pollination is reliable but flexible, receiving a wide variety of species with different behaviors (Biffin et al., 2010; Sabino et al., 2018). The fruits are elliptical, fleshy and succulent, berry-type, with purplish-black pericarp and purple mesocarp, with only one seed inside (Alberto et al., 2001). The exotic flavor of the fruit is because of the presence of organic acids, tannins, and other phenolic compounds, which give it an acid and astringent flavor. In Northern Asia, the fruit ripens between June and July, while in Brazil the ripened fruits can be found between December and February (Sabino et al., 2018).

Species of the *Syzygiaeae* genus have recognized economic power, as they have the potential for medicinal and food use, besides to its significant biological activity (Ranghoo-Sanmukhiya et al., 2019). *S. cumini* is a source of antioxidants, bioactive compounds, and natural nutrients,

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**Table 1**  
Nutritional composition of *S. cumini* pulp.

Components	Brazil <sup>1</sup>	Brazil <sup>2</sup>	India <sup>3</sup>	Brazil <sup>4</sup>	Pakistan <sup>5</sup>	Bangladesh <sup>6</sup>
pH	3.79 ± 0.01	–	–	3.22 ± 0.04	–	–
Titratable acidity (g citric acid/100 g)	0.65 ± 0.02	–	–	5.25 ± 0.08	–	–
Total soluble solids (°Brix)	–	–	–	13.00 ± 0.11	14.31	–
Proximate composition (g/100 g)						
Moisture	87.20 ± 0.30	81.7 ± 3.6	85.0	85.32 ± 0.91	85.69	77.20 ± 2.4
Protein	0.85 ± 0.05	0.80 ± 0.1	0.99	0.75 ± 0.08	0.72	0.60 ± 0.02
Lipids	0.49 ± 0.02	–	0.24	0.27 ± 0.01	0.27	0.10
Ashes	0.23 ± 0.08	0.42 ± 0.1	0.68	0.32 ± 0.02	0.32	–
Carbohydrate	11.40	–	–	–	17.37	19.50 ± 0.4
Dietetic Fiber	–	0.40 ± 0.4	0.11	0.27 ± 0.04	0.22	0.90 ± 0.06
Total energy value (Kcal/100 g)	48	61	–	–	–	–

Results are expressed as mean ± SD. References: <sup>1</sup> Brito et al. (2017); <sup>2</sup> Barcia et al. (2012); <sup>3</sup> Benherlal and Arumughan (2007); <sup>4</sup> Vital et al. (2020); <sup>5</sup> Shahnawaz et al. (2009); <sup>6</sup> Paul and Shaha (2004).

and is used for direct consumption or as a promising raw material for the pharmaceutical and food industry (Seraglio et al., 2018). Its wood is very strong and resistant, contributing to the manufacture of firewood and charcoal (Sabino et al., 2018). The edible pulp can be used in the preparation of jam, jelly, juice, ice cream, vinegar, wine and pudding (Nuengchamnong and Ingkaninan, 2009; Oliveira et al., 2016; Venugopal and Anu-Appaiah, 2017; Venugopal et al., 2018). While its leaves serve as food for silkworms or can be used for the extraction of essential oils in the production of perfumes and soaps. The flowers, rich in nectar, are useful for beekeeping, since they collaborate to the production of high-quality honey (Sabino et al., 2018). In addition, the peel and seeds are used in Ayurvedic, Unani and Chinese medicines as a natural alternative for the treatment of dysentery, hyperglycemia, glycosuria, ulcers, bronchitis, asthma, among others (Chaudhary and Mukhopadhyay, 2012). According to Chhikara et al. (2018), all parts of the plant have several health benefits, such as hypoglycemic, anti-inflammatory, antianemic, antibacterial, antioxidant, antiallergic, hepatoprotective, hypolipidemic and antipyretic properties.

**Table 2**  
Anthocyanins of *S. cumini* pulp and peel.

Anthocyanins	Pulp and peel <sup>a</sup> peel <sup>b</sup> (mg/ 100 g, d.w.)	Pulp and peel <sup>c</sup> (mg/ 100 g, f.w.)	Pulp and peel <sup>d</sup> (mg/ 100 g, d.w.)	Pulp <sup>e</sup> (mg/ 100 g, d.w.)	Peel <sup>f</sup> (mg/ g, f. w.)	Peel powder <sup>g</sup> (mg/ 100 g, d. w.)
Delphinidin 3,5-O-diglc	256.0 4.2	95.6 ± ± 12.9	503.5 ± 0.0	4.0 ± 0.0	3.8 ± 0.0	23.9 ± 0.9
Delphinidin- 3-O-glcl	–	–	30.8 ± 0.8	0.1 ± 0.0	0.2 ± 0.0	–
Delphinidin acetyl- diglc	–	0.4 ± 0.0	–	–	–	–
Cyanidin 3,5-O-diglc	29.0 –	0.8 ± 0.4 –	35.6 ± 0.7	0.3 ± 0.0	0.3 ± 0.0	5.6 ± 0.2
Cyanidin 3- O-glcl	–	–	–	0.02 ± 0.0	0.04 ± 0.0	–
Petunidin 3,5-O-diglc	245.0 1.7	68.0 ± 1.1	– 385.6	3.0 ± 0.0	3.3 ± 0.0	44.6 ± 1.7
Petunidin 3- O-glcl	–	1.1 ± 0.0	–	– ± 6.6	– ± 0.0	–
Peonidin 3,5- O-diglc	75.0 –	4.7 ± 0.7 0.4	14.6 ± ± 0.0	0.6 ± 0.0	0.1 ± 0.0	1.5 ± 0.1
Malvidin 3,5-O-diglc	166.0 1.5	32.0 ± ± 3.8	268.3 ± 0.0	2.4 ± 0.0	2.3 ± 0.0	48.0 ± 1.8
Malvidin 3- O-glcl	–	0.4 ± 0.1	–	0.01 ± 0.0	0.02 ± 0.0	–
<b>TOTAL</b>	<b>771.0</b> <b>9.1</b>	<b>210.9 ±</b> <b>± 24.7</b>	<b>1318.4</b> <b>± 0.2</b>	<b>0.6</b> <b>± 0.5</b>	<b>24.6</b> <b>± 0.5</b>	<b>124.1 ±</b> <b>4.8</b>

Results are expressed as mean ± SD. References: <sup>1</sup> Brito et al. (2007); <sup>2</sup> Faria et al. (2011); <sup>3</sup> Lestario et al. (2017); <sup>4</sup> Tavares et al. (2016); <sup>5</sup> Peixoto et al. (2016). d.w., dry weight; f.w., fresh weight.

The edible part of the fruit stands out for its contents of phenolic compounds, mainly galloyl glucose and gallic acid, and for its levels of total monomeric anthocyanins, which can play an important biological activity, especially in combating free radicals (Rufino et al., 2010; Seraglio et al., 2018). In addition, the fruit may contain important minerals for human health, such as magnesium and potassium (Seraglio et al., 2018). The high density of nutrients and bioactive compounds has attracted the attention of researchers worldwide, as to the use of the fruit as a functional food. Thus, this review proposes a general view regarding the nutritional and health benefits aspects, and the health benefits of the main components of jambolan fruit.

## 2. Macronutrients and minerals composition

Studies from different parts of the world analyzed the nutritional aspects of the *S. cumini* pulp, carried out especially in Bangladesh, Brazil, India and Pakistan. The pulps stand out for their considerable moisture content and carbohydrates (Table 1), and low total energy value.

Regarding the composition of sugars, the *S. cumini* pulp has 11.23 g/100 g (w.w.) of total sugars, which are divided between fructose (6.20 g/100 g) and glucose (5.03 g/100 g) (Seraglio et al., 2018). These levels are highly influenced by the ripening stage, since they present an increase between 22% and 35% when completing their ripening (Seraglio et al., 2018). Further, Barcia et al. (2012) found 27.9 ± 1.2% of reducing sugars and 0.65 ± 0.1% of pectin in the pulp of *S. cumini*, while Benherlal and Arumughan (2007) reported the presence of 5.23 g/100 g of starch. These high levels of sugars allow the use of the fruit as an ingredient in other products, mainly in the production of yogurt, jellies and fermented drinks such as wine (Nuengchamnong and Ingkaninan, 2009; Oliveira et al., 2016; Venugopal and Anu-Appaiah, 2017; Venugopal et al., 2018).

Concerning the mineral composition, according to Seraglio et al. (2018), which analyzed jambolan fruits from Brazil, the dry pulp presents 5.9 g/100 g of total minerals, standing out for the presence of potassium (3.8 g/100 g), calcium (1.04 g/100 g), magnesium (0.78 g/100 g) and sodium (0.31 g/100 g). These mineral contents are similar to that of the jabuticaba (*Myrciaria cauliflora*), which has a content of 5.7 g/100 g total minerals, with potassium being the predominant mineral (4.5 g/100 g), but contents much lower than those of the guabiju (*Myrcianthes pungens*), which has 12.6 g/100 g of total minerals, highlighting the levels of potassium (9.6 g/100 g) and calcium (2.3 g/100 g) (Seraglio et al., 2018). Other researchers who analyzed the mineral content in jambolan pulp were Paul and Shaha (2004), who studied native fruits from Bangladesh. According to them, the fresh pulp of *S. cumini* (77.2% of moisture) has 0.023

g/100 g of magnesium, 0.02 g/100 g of calcium, 0.016 g/100 g of sodium, 0.01 g/100 g of phosphorus and 0.01 g/100 g of iron.

The ripening process directly influences the contents of these minerals, causing a reduction of 18% in the levels of total minerals, mainly in the contents of potassium (26%) (Seraglio et al., 2018). The nutrients present in the soil, especially sodium, aluminum and sulfur, as well as their potential acidity, have a direct influence on the nutrients that can be found in the leaves (N, Mn, Co, Fe, S and Mg), which can also occur with the pulp. However, precipitation and temperature have a low influence on the composition of these minerals (Rezende et al., 2013). Furthermore, abiotic and biotic factors such as soil-climate adaptation and nutrient availability as factor of soil fauna, also shows how mineral contents varies (Dwivedi et al., 2019).

### **3. Bioactive compounds of *S. cumini***

#### **3.1. Anthocyanins**

The edible portion of *S. cumini* has a total anthocyanin content ranging from 28.5 to 1318.4 mg/100 g (f. w.), depending on the ripening stage and its consequent coloring, which can vary from green-yellow to black (Lestario et al., 2017). Since the accumulation of this pigment in the fruit cells happen throughout the ripening process (Seraglio et al., 2018), 97% of these compounds are found in the peel, not in the pulp of the edible portion of *S. cumini* (Tavares et al., 2016). When compared to other tropical fruits found in Brazil, jambolan presents intermediate levels of anthocyanin, which are higher than the levels found in acerola (*Malpighia emarginata*) and jambo (*Syzygium jambos*), but less than the levels found in guajiru (*Chrysobalanus icaco*), juçara (*Euterpe edulis*) and jaboticaba (*M. jaboticaba* (Vell.) O. Berg) (Brito et al., 2007; Peixoto et al., 2016). Despite not being fruits of the same family, this comparison is relevant when considering the availability and access of the local population to the fruits.

Regarding the anthocyanin profile, studies report the presence of delphinidin, cyanidin, petunidin, peonidin and malvidin in the pulp and peel of *S. cumini* (Table 2). Throughout the fruit ripening, delphinidin is the predominant anthocyanin, responsible for 37–48% of the total anthocyanins, followed by petunidin (29–33%) and malvidin (19–27%), while cyanidin (3%) and peonidin (1–2%) are found in lower levels (Lestario et al., 2017). Another factor that directly influences anthocyanin contents is the product storage period. In dehydrated peels, these compounds show a 10% reduction after two months of being stored and 36% after 5 months (Santiago et al., 2016).

Studies prove that delphinidin, the phenolic compound found in higher concentration in *S. cumini*, has a potent antioxidant action, by increasing the nuclear translocation of Nrf2 and inhibiting its degradation in HepG2 cells (Xu et al., 2020); and by inhibiting apoptosis induced by reactive oxygen species, as they significantly reduce apoptosis markers, such as c-caspase-3 and c-PARP, in addition to increasing the anti-apoptotic marker Bcl-XL and the antioxidant response pathways NF-κB and Nrf2 (Lee et al., 2020). Besides, it shows antiviral properties against the (V'azquez-Calvo et al., 2017).

Moreover, studies with petunidin, a β-ring 5'-O-methylated derivative of delphinidin, describe that this anthocyanin also has antioxidant action by decreasing the concentration of reactive oxygen species (Cai et al., 2020; Yan et al., 2020), besides to the presenting other functions, such as reducing osteopenia by stimulates the osteoblastogenesis and suppress bone resorption (Nagaoka et al., 2019).

**Table 3**  
Non-anthocyanic phenolic compounds (mg/100 g) of *S. cumini* pulp and peel.

Non-anthocyanic phenolic compounds	Pulp and peel <sup>1</sup> (d.w.)	Pulp and peel <sup>2</sup> (d.w.)	Pulp <sup>3</sup> (f.w.)	Peel <sup>3</sup> (f.w.)
<b>Flavonoids</b>				
Dihydromyricetin diglc	2.80 ± 0.24	—	6.45	5.36
Methyldihydromyricetin diglc	2.00 ± 0.15	—	1.68	2.06
Dimethyldihydromyricetin diglc	2.90 ± 0.07	—	—	0.57
Myricetin-3-O-hexoside	3.20 ± 0.32	—	—	—
Myricetin-3-O-pentoside	2.30 ± 0.32	—	1.15 ± 0.01	0.32 ± 0.00
Myricetin-3-O-rhamnoside	4.20 ± 0.43	—	1.01 ± 0.01	1.19 ± 0.00
Myricetin-3-O-glucoride	—	—	0.75 ± 0.02	0.30 ± 0.00
Myricetin-3-O-galactoside	—	—	0.25 ± 0.00	0.18 ± 0.00
Myricetin-3-O-glucoside	—	—	3.03 ± 0.02	0.64 ± 0.01
Laricitrin-3-O-galactoside	—	—	0.50 ± 0.01	0.16 ± 0.00
Laricitrin-3-O-glucoside	—	—	0.58 ± 0.02	0.50 ± 0.00
Dihydroquercetin-dihexoside	—	—	0.61 ± 0.06	0.69
Methyl-dihydroquercetin-dihexoside	—	—	0.14 ± 0.52	0.12 ± 0.19
Isoquercitrin	—	0.01 ± 0.00	—	—
Naringenin	—	0.04 ± 0.00	—	—
Quercetin	—	0.04 ± 0.00	—	—
Pinobanksin	—	0.04 ± 0.00	—	—
<b>Other phenolic compounds</b>				
p-Coumaric acid	—	0.05 ± 0.00	—	—
3,4-Dihydroxybenzoic acid	—	0.04 ± 0.00	—	—
Syringic acid	—	0.13 ± 0.00	—	—
Galloyl glucose	21.39 ± 0.92	—	0.82 ± 0.00	4.23 ± 1.98
Galloyl glucose derivatives	34.01	—	12.34	29.50
Gallic acid	38.30 ± 1.00	11.20 ± 0.09	0.82 ± 0.00	2.41 ± 1.98
Ellagic acid	1.10 ± 0.15	—	0.24 ± 0.06	1.40 ± 0.34
Ellagic acid-pentoside	—	—	0.08 ± 0.01	0.09 ± 0.01
Di-Hexahydroxydiphenoyl-glc-1	—	—	1.53 ± 0.05	1.31 ± 0.20
Di-Hexahydroxydiphenoyl-glc-2	—	—	1.04 ± 0.19	0.77 ± 0.15
Galloyl-di-Hexahydroxydiphenoyl-glc-1	—	1.20 ± 0.13	2.00 ± 0.11	—
Galloyl-di-Hexahydroxydiphenoyl-glc-2	—	—	—	3.87 ± 1.8
Di-galloyl-Hexahydroxydiphenoyl-glc	—	0.60 ± 0.08	—	1.27
Tri-galloyl-Hexahydroxydiphenoyl-glc	—	—	—	1.67 ± 0.37
Trisgalloyl-Hexahydroxydiphenoyl-glc-1	—	—	1.40 ± 0.19	2.38 ± 0.67
Trisgalloyl-Hexahydroxydiphenoyl-glc-2	—	—	1.10 ± 0.21	3.04 ± 0.66
Vescalagin	—	—	2.66 ± 0.64	1.00 ± 0.24
Castalagin	—	—	0.82 ± 0.21	0.67 ± 0.10
<b>TOTAL</b>	<b>114.00</b>	<b>11.60</b>	<b>11.18</b>	<b>45.36</b>

Results are expressed as mean ± SD. References: <sup>1</sup> Lestario et al., (2017); <sup>2</sup> Seraglio et al. (2018); <sup>3</sup> Tavares et al. (2016). d.w., dry weight; f.w., fresh weight.

Only two study regarding the bioaccessibility of bioactive compounds from the consumption of jambolan was found. The first study was carried out with dehydrated *S. cumini* peel at 60 °C for 22 h. The peel was submitted to in vitro digestion simulating the oral, gastric, and small intestinal phases. The anthocyanin's bioaccessibility after gastric digestion was 65%, while intestinal bioaccessibility was 45%. These results were 3–5 times greater than the dehydrated peels of jabuticaba and jambo analyzed in the same study under the same conditions (Peixoto et al., 2016), confirming that jambolan is a good source of bioavailable anthocyanins. The most recent study describes the bioaccessibility of some bioactive compounds from jambolan pulp after simulating oral, gastric, duodenal and colonic digestion. However, they did not evaluate the behavior of anthocyanins (Sousa et al., 2021).

### 3.2. Non-anthocyanic phenolic compounds

Phenolic compounds are molecules that have one or more hydroxyl groups linked to an aromatic ring (polyphenol), being classified according to the number of carbons in the molecule (Marchiosi et al., 2020). Polyphenols oxidize easily when exposed to sunlight or oxygen, which leads to proton abstraction, generating radicals that can react with other radicals to form dimers. In addition, contact with reactive oxygen species or the action of oxidoreductases, peroxidases and monophenol monooxygenase can lead to the oxidation of these compounds (Vermerris and Nicholson, 2006). The scientific literature has associated the antioxidant action of polyphenols with several benefits against neurodegenerative diseases, cancer, cardiovascular diseases, metabolic disorders and autoimmune diseases (Dias et al., 2020).

The edible part of *S. cumini* has a significant concentration of total phenolic compounds, ranging from 995 to 1117 mg GAE/100 g (d. w.) (Reynertson et al., 2008; Rufino et al., 2010). Concerning the determination of non-anthocyanin phenolic compounds, the peel has 4 times more compounds than the pulp (Tavares et al., 2016). There are studies, which have identified flavonoids, flavones, gallotannins and ellagitannins in the edible part of the fruit. Among these, the compounds found in higher concentrations were gallic acid, galloyl glucose and hexahydroxydiphenol and their derivatives (Table 3).

The gallic acid, a trihydroxybenzoic acid, suppress lipogenesis, improve insulin signaling, improved inflammatory response via NF-κB pathway, combat oxidative stress, and has antifungal activity (Dludla et al., 2019; Li et al., 2017; Zhu et al., 2019). On the other hand, studies have shown that the galloyl glucose exhibits great potential in the therapy and prevention of cancer and diabetes. Potential mechanisms include anti-angiogenesis, anti-proliferative actions, anti-inflammation, anti-oxidation, and induction of apoptosis (Zhang et al., 2009).

When ripening, the primary metabolism of the fruit is reduced, resulting in the lack of essential substrates for the biosynthesis of these compounds, which causes a decline in their levels (Seraglio et al., 2018). It was found that, with ripening, flavonols reduce in approximately 60%, gallotannins in about 35% and ellagitannins in 11%. Only flavanols increase during the ripening process, from 0 to 7.7 mg/100 g (d. w.) (Lestario et al., 2017).

After simulated digestion, Sousa et al. (2021) reported that total phenolic compounds become more bioaccessible after the gastric phase (677.13 mg GAE/100 g; 58.23%), followed by the duodenal phases (535.64 mg GAE/100 g; 28.86%), oral (309.82 mg GAE)/100 g; 26.64%), and colonic (47.87 mg GAE/100 g; 4.12%). While flavonoids become more bioaccessible after the duodenal phase (118.59 mg GAE/100 g; 192.67%), followed by the gastric phases (84.17 mg GAE/100 g; 51.81%), oral (75.25 mg GAE/100 g; 46.32%), and colonic (10.31 mg GAE/100 g; 6.34%). Flavones are found only in the gastric (2.52 mg GAE/100 g; 8.71%) and oral (1.06 mg GAE/100 g; 3.66%) phases. Finally, proanthocyanidins have a behavior similar to phenolics, becoming more bioaccessible after the gastric phase (174.46 mg GAE/100 g; 111.61%), followed by the duodenal phases (174.46 mg GAE/100 g; 90.93%), oral (134.27 mg GAE/100 g; 69.98%), and colonic (9.26 mg GAE/100 g; 4.82%).

### 3.3. Carotenoids

Carotenoids are lipophilic pigments produced by the secondary metabolism of photosynthetic bacteria and some species of plants, animals, algae, and fungi (Maoka, 2019). Chemically, they are tetraterpenes with conjugated double bonds. Moreover, some compounds have, at least, one unsubstituted  $\beta$ -ion ring, with a polyenic side chain, which can be converted into retinols, being called provitamin A (Maoka, 2019; Yahia et al., 2018). They have been related to several benefits to human health, presenting numerous therapeutic effects, including anticancer, immunomodulators, anti-inflammatory, antibacterial, antidiabetic and neuroprotective (Nabi et al., 2020). So, the identification of these foods is extremely important.

Only two studies were found in the literature describing the carotenoid profile of jambolan (Table 4). Barcia et al. (2012) studied fruits collected in 3 different regions of Rio Grande do Sul, Brazil, and found lutein, zeaxanthin and  $\beta$ -cryptoxanthin. On the other hand, Faria et al. (2011), reported that the edible part of the fruit stood out for the presence of all-trans-lutein and all-trans- $\beta$ -carotene, representing 43.7% and 25.4% of the total carotenoid content of the edible pulp, respectively. Considering this information, we proposed a pathway for the biosynthesis of carotenoids in buriti pulp (Fig. 1).

**Table 4**  
Carotenoids ( $\mu\text{g}/100 \text{ g}$ ) of *S. cumini* pulp and peel.

Carotenoids	Pelotas, Brazil <sup>1</sup> (f.w.)	Capão do Leão, Brazil <sup>2</sup> (d.w.)	Pelotas, Brazil <sup>2</sup> (d.w.)	Santa Vitória do Palmar, Brazil <sup>2</sup> (d.w.)
cis-Neoxanthin or cis-violaxanthin	0.6 $\pm$ 0.0	–	–	–
cis-Lutein	1.3 $\pm$ 0.1	–	–	–
cis-Lutein	0.7 $\pm$ 0.1	–	–	–
All-trans-lutein	39.0 $\pm$ 2.2	–	–	–
All-trans-zeaxanthin	1.7 $\pm$ 0.0	–	–	–
Lutein + zeaxanthin	–	211.0	576.0	513.0
Phytoene	5.6 $\pm$ 0.9	–	–	–
All-trans- $\beta$ -cryptoxanthin	0.3 $\pm$ 0.1	99.0	94.0	133.0
Phytofluene	2.9 $\pm$ 0.0	–	–	–
15-cis- $\beta$ -Carotene	3.1 $\pm$ 0.1	–	–	–
13-cis- $\beta$ -Carotene	3.8 $\pm$ 0.0	–	–	–
All-trans- $\alpha$ -carotene	2.7 $\pm$ 0.0	–	–	–
All-trans- $\beta$ -carotene	22.7 $\pm$ 1.6	–	–	–
9-cis- $\beta$ -Carotene	4.9 $\pm$ 0.2	–	–	–
<b>TOTAL</b>	89.2 $\pm$ 5.4	311.0	668.0	647.0

Results are expressed as mean  $\pm$  SD. Reference: <sup>1</sup> Faria et al. (2011); <sup>2</sup> Barcia et al. (2012).

The antioxidant activity of lutein is well established in the scientific literature, but recent studies have reported its potential in combating visual disorders, filtering blue light and assisting in the formation of macular pigments, in addition to playing a role in the regulation of cell signal transduction pathway through its antioxidant, anti-inflammatory effects as well as the conduction velocity of nerve cells, improving the cognitive function of humans (Jia et al., 2017; Renzi-Hammond et al., 2017).

Only lutein, zeaxanthin, meso-zeaxanthin and their oxidative metabolites are selectively accumulated in the macula lutea region of the human retina. Thus, these carotenoids were classified as macular pigments, since the specific binding proteins of lutein and zeaxanthin (StARD3 and GSTP1, respectively) mediate selective uptake in this region of the retina. This stands out because these carotenoids filter the short and high-intensity visible light waves and present antioxidant action in this region, so vulnerable to light-induced oxidative stress (Arunkumar et al., 2020).

$\beta$ -carotene is a potent antioxidant with protective action against cardiovascular diseases. LDL-cholesterol oxidation is a crucial factor for the development of atherosclerosis and  $\beta$ -carotene acts by inhibiting the lipoprotein oxidation process (Ambr'osio et al., 2006).

More studies are needed regarding the carotenoid profile of jambolan as well as the bioaccessibility of these compounds, in order to make public the knowledge of the contents.

### 4. Food science and technology

The presence of tannins and phenolic compounds, as well as their high sugar content, are characteristics that favor the production of wine from the pulp of *S. cumini*, which can be made with or without the seeds. This results in a product with an alcohol content of approximately 8–10%, 3–5 °Brix, pH between 3.4 and 3.78 and 0.51–2.43 g/L of malic acid. During the vinification process, there is a reduction in the concentration of total sugars, malic acid, total phenolic compounds, total flavonoids and tannins. These factors directly influence the organoleptic characteristics of the final product,

which presents less astringency and less intense coloration after the aging process (Venugopal and Anu-Appiah, 2017; Venugopal et al., 2018). Moreover, studies have reported the presence of tartaric acid, citric acid, gallic acid, ellagic acid, catechin, chlorogenic acid, vanillin and ferulic acid in the wine and the fermented alcoholic drink produced with jambolan pulp, which, when compared with other fermented alcoholic beverages, stood out for the considerable levels of gallic acid (51.5–99.43 mg/L) (Nuengchamnong and Ingkaninan, 2009; Oliveira et al., 2016).

Lago et al. (2006), when observing better acceptance of the product by the consumers market, proposed the standardization in the production of jambolan jam with the ratio between peeled pulp and water of 0.7:0.3 and between peeled pulp and sugar of 0.6:0.4, to obtain 67 °Brix. Besides, they reported the need to add citric acid to correct the pH to 3.4%, and 1% of pectin. The global evaluation carried out by 50 evaluators proved to be satisfactory, and the parameter that most pleased the evaluators was the coloring. Regarding the use of dehydrated pulp as an additional ingredient, there are reports of the use of *S. cumini* pulp as a yogurt coloring and as an ingredient in pasta production. Despite the attractive coloring added to the yogurt, the evaluators did not express great satisfaction with the yogurt added with the freeze-dried pulp of jambolan, reporting a major change in the taste of the final product (Freitas-Sá et al., 2018).

Regarding the pasta produced with jambolan pulp, different proportions of flour incorporation were tested, applying from 0% to 40% of pulp. Contrary to what was observed for the yogurt, the evaluators showed good acceptance in any concentration of jambolan, but the best was with the use of 30% of *S. cumini* flour, which presented the best scores for color (8.1), flavor (8.16), taste (7.83), texture (7.1), mouth feel (8.6) and general acceptance (8.1). The researchers also reported that the use of jambolan flour improved the nutritional quality of the pasta by considerably increasing the content of ash, crude fiber, antioxidants, β-carotene, total phenolics and tannic acid (Panghal et al., 2019). To improve the acceptance of consumers, astringency can be reduced. In order to do so, 98 kPa of N<sub>2</sub>, 100 ppm of ethylene or 3.38 mL of absolute ethanol/L can be applied to the fruit during the final stage of ripening, in order to reduce the concentration of tannins present in the pulp of *S. cumini* (Severo et al., 2010).

## 5. Health benefits

The pulp and seed of *S. cumini* demonstrated inhibition of intestinal glucose loading and a remarkable reduction in the concentration of blood glucose and glycated hemoglobin, as well as a significant improvement in serum insulin, HOMA-IR, C-peptide levels, and in the activity of hexokinase, phosphofructokinase, glucose-6-phosphatase and fructose-1,6-bisphosphatase in the animals studied. Besides, a protective effect against DNA degeneration in the pancreatic β-cells of diabetic rats has been proven. Studies have reported that the best effect has been seen in higher concentrations of the water extracts (Table 5).

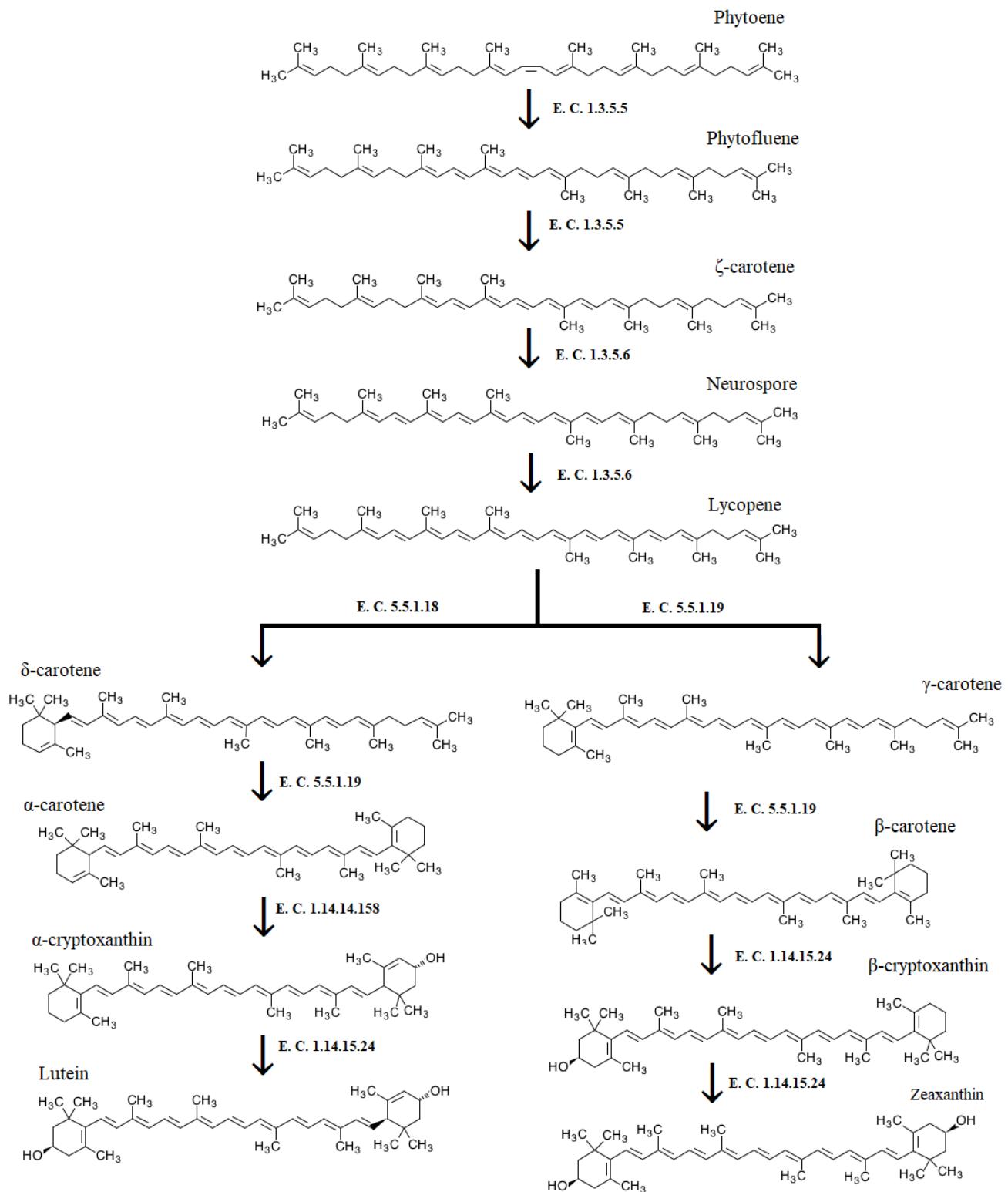
Animal studies have reported that supplementation with pulp or seeds extract of jambolan can reduce serum levels of triglycerides, total cholesterol, LDL-c and VLDL-c, and also increase

HDL-c content (Table 5). A reversal in the concentration of sVCAM-1 and fibrinogen close to normal has been reported, as well as an increase in the total concentration of nitric oxide (Tanwar et al., 2011). Also, Rekha et al. (2008) found a reduction in lipid peroxidation and in the presence of hydroperoxides, which are associated with several pathological processes related to DNA damage (Yang and Schaich, 1996).

Oral supplementation with pulp or seeds extract of *S. cumini* significantly improves the action of antioxidant enzymes (superoxide dismutase, catalase and glutathione peroxidase) and regulates the contents of thiobarbituric acid-reactive substances (TBARS) and TNF-α (Table 5).

Regarding hepatoprotective activity, experimental treatments with jambolan reported decreased levels of bilirubin and liver enzymes (alanine aminotransferase, glutamic oxalacetic transaminase and alkaline phosphatase), increased concentration of total proteins and albumin, and preservation of the histological structure of liver tissue (Table 5).

A study that evaluated oral supplementation of *S. cumini* seeds in male albino Wistar rats reported an effect comparable to that of animals treated with a standard drug (piracetam), showing improvement in cognitive deficit and memory (Alikatte et al., 2012).



**Fig. 1.** Proposed pathway for carotenoid biosynthesis in *S. cumini*, based on the compounds identified in the literature (shown in Table 4), data available in the KEGG (Kyoto Encyclopedia of Genes and Genomes) database of carotenoid biosynthesis (<https://www.genome.jp/kegg/pathway.html>). Enzymes: E. C. 1.3.5.5 = phytoene desaturase; E. C. 1.3.5.6 =  $\zeta$ -carotene desaturase; E. C. 5.5.1.18 = lycopene  $\delta$ -cyclase; E. C. 5.5.1.19 = lycopene  $\beta$ -cyclase; E. C. 1.14.14.158 = carotenoid  $\delta$ -hydroxylase; E. C. 1.14.15.24 =  $\beta$ -carotene 3-hydroxylase.

**Table 5**

Summary of experimental studies (animal models) investigating the effects of jambolan supplementation on health.

Supplement	Animals	Study design	Biological effects	References
<i>S. cumini</i> seeds and pulp	Sprague Dawley rats.	Normal: 60 days; 3 groups (n = 5): (1) control; (2) 3% of lyophilized seed powder; (3) 3% of lyophilized pulp powder.  Hyperglycemic: 60 days; 3 groups (n = 5): (1) control + 40% sucrose; (2) 3% of lyophilized seed powder + 40% sucrose; (3) 3% of lyophilized pulp powder + 40% sucrose.	Antidiabetic effect: low blood glucose concentrations were observed in both treated groups after 60 days. Better results were observed in the seed-treated rats. The diet affected insulin level momentously.	<sup>1</sup>
<i>S. cumini</i> pulp	Female Wistar rats (170 g) with diabetes (STZ: 55 mg/kg)	15 days; 5 groups (n = 6): (1) control – citrate buffer (0.01M, pH 4.5); (2) diabetic control; (3) <i>S. cumini</i> (100 mg/kg, orally); (4) <i>S. cumini</i> (200 mg/kg, orally); (5) Glyburide (5 mg/kg, orally).	Antidiabetic effect: the treated rats showed weight maintenance and reduced blood glucose levels.  Hypolipidemic effect: protection against changes in the lipid profile, and reduced lipid peroxidation and hydroperoxides was observed.  Effect on antioxidant activity: the activity of antioxidant enzymes (superoxide dismutase and catalase) was reversed close to normal.  The results demonstrated dose-dependence.	<sup>2</sup>
<i>E. jambolana</i> pulp	Male albino Wistar rats (160-200 g) with diabetes (STZ: 45 mg/kg).	30 days; 6 groups (n = 7): (1) healthy control; (2) diabetic control + atherosclerotic diet; (3) diabetic + Ath diet + Glibenclamide (600 µg/kg); (4) diabetic + Ath diet + hypoglycemic compound isolated from the aqueous extract of <i>E. jambolana</i> pulp (FII) (10mg/kg); (5) diabetic + Ath diet + FII (15 mg/kg); (6) diabetic + Ath diet + FII (20 mg/kg).	Antidiabetic effect: dose-dependent glycemic control with noticeable decrease.  Hypolipidemic effect: significant reduction in the levels of triglycerides, total cholesterol, LDL-c and VLDL-c; increase in HDL-c levels; reverted back the sVCAM-1 and fibrinogen levels to near normal; increase in levels of total nitric oxide; and normal histology of heart was observed.	<sup>3</sup>
<i>E. jambolana</i> pulp	Male Wistar albino rats (160-200 g) with diabetes (STZ: 45 mg/kg).	8 weeks; 6 groups (n = 5): (1) control; (2) diabetic control; (3) diabetic + hypoglycemic compound isolated from the aqueous extract of <i>E. jambolana</i> pulp (FII) (10mg/kg); (4) diabetic + FII (15 mg/kg); (5) diabetic + FII (20 mg/kg); (6) diabetic + glibenclamide (600 µg/kg).	Antidiabetic effect: groups 4 and 5 showed a significant reduction in blood glucose and glycated hemoglobin levels and significantly improved serum insulin, C-peptide levels, and in the activity of hexokinase, phosphofructokinase, glucose-6-phosphatase and fructose-1,6-bisphosphatase.  Hypolipidemic effect: was comparable to that of glibenclamide.  Effect on antioxidant activity: the activity of superoxide dismutase and catalase was significantly improved.	<sup>4</sup>
<i>E. jambolana</i> pulp	Albino rabbits (1.0-1.5 kg) with diabetes (Alloxan: 80 mg/kg)	Normal: 3 groups (n = 5): (1) control - vehicle treated; (2) water extract (100 mg/kg); (3) ethanolic extract (100 mg/kg).  Diabetic: 7 days. 4 groups (n = 5): (1) untreated; (2) tolbutamide (250 mg/kg); (3) water extract (100 mg/kg); (4) ethanolic extract (100 mg/kg).  Severely diabetic: 15 days. 4 groups (n = 5): (1) untreated; (2) tolbutamide (250 mg/kg); (3) water extract (100 mg/kg); (4) ethanolic extract (100 mg/kg).	Antidiabetic effect: the water extract was more effective than the ethanol extract in reducing fasting blood glucose and peak blood glucose during glucose tolerance test. Best results have been seen in severely diabetic rabbits. The effect of the water extract was comparable to the effect produced of the standard drug.	<sup>5</sup>

<i>E. jambolana</i> pulp	Adult Wistar albino rats (100-150 g).	10 days; 5 groups (n = 6): (1) control – 3% gum acacia (5ml/kg, orally) for ten days; (2) Paracetamol-treated control – 3% gum acacia for 10 days + on the eighth day, hepatotoxicity was induced in these rats by giving a single dose of paracetamol suspension (2gm/kg, orally); (3) <i>E. jambolana</i> extract (100 mg/kg, orally), for ten days; (4) <i>E. jambolana</i> extract (200 mg/kg, orally), for ten days; (5) Silymarin (100 mg/kg, orally). On the eighth day of the experiment, hepatotoxicity was induced in Groups 3, 4, 5 also.	Hepatoprotective activity: pretreatment with <i>E. jambolana</i> , in both doses, reduced the levels of enzymes, increased the levels of total protein and albumin, and preserved the histological structure of the liver to near normal.  <sup>6</sup>
<i>S. cumini</i> seeds	Wistar albino rats of either sex (230- 250 g), 8- 10 weeks of age with diabetes (Alloxan: 150 mg/kg).	14 days; 5 groups (n = 6): (1) control – only vehicle; (2) Diabetic control – only vehicle; (3) Diabetic + methanolic extract of <i>S. cumini</i> seeds (100 mg/kg, p.o.); (4) Diabetic + methanolic extract of <i>S. cumini</i> seeds (200 mg/kg, p.o.); (5) Diabetic + gliclazide (25 mg/kg, p.o.).	Antidiabetic effect: glucose levels were reduced significantly and serum insulin levels also improved.  Hypolipidemic effect: it was observed a reduction in total cholesterol, LDL-c and serum triglyceride, and increased serum HDL-c.  <sup>7</sup>
<i>S. cumini</i> seeds	Male Wistar albino rats (150- 200 g) 12-14 weeks old (STZ: 40 mg/kg)	21 days; 5 groups (n = 10): (1) control – saline (5.0 ml/kg, p.o.); (2) positive control – diabetic rats + saline; (3) diabetic + <i>S. cumini</i> (100 mg/kg; 200 mg/kg; 400 mg/kg); (4) diabetic + Aegle marmelos (500 mg/kg) + <i>S. cumini</i> (200 mg/kg); (5) diabetic + Metformin (100 mg/kg).	Hepatoprotective activity: the extract treatment did not show any statistically significant reduction in serum creatinine and serum urea. However, the protein concentration increased significantly, even more than that of the rats treated with the gliclazide, and it was observed a reduction in the ALT, AST, ALP and bilirubin levels. A liver section revealed normal hepatic tissue.  <sup>8</sup>
<i>S. cumini</i> seeds	Male Wister albino rats (150- 200 g), 2- 3 months of age	4 weeks; 4 groups (n = 6): (1) control - citrate buffer (0.1, pH 4.5; i.p); (2) positive control – STZ-induced diabetic rats. (3) STZ-induced diabetic rats + 200 mg <i>S. cumini</i> /kg b.w. orally, once weekly. (4) STZ-induced diabetic rats + 200 mg <i>C. zeylanicum</i> /kg b.w. orally, once weekly.	Antidiabetic effect: there was a significant reduction in serum glucose, insulin and HOMA-IR. The supplementation had a protective effect on β-cells of diabetic rats, evidenced by an increased number of secretory granules and normal architecture of nuclei and mitochondria. The effect was dose-dependent.  Hypolipidemic effect: the levels of total cholesterol, triglyceride and LDL-c were reduced significantly, and an increased level of HDL-c was observed.  Effect on antioxidant activity: the levels of superoxide dismutase, catalase and glutathione peroxidase increased. The contents of thiobarbituric acid-reactive substances and TNF-α decreased.  <sup>9</sup>

			glutathione peroxide, reduced glutathione and thiobarbituric acid-reactive substances were reversed significantly to near normal
E.	<i>jambolana</i> seeds	Male albino Wistar rats (120 g), 12 weeks of age.	Hepatoprotective activity: the serum glutamic oxaloacetic transaminase and serum glutamic pyruvic transaminase significantly decreased.
S.	<i>cumini</i> seeds	35 days; 4 groups (n = 6): (1) control – citrate buffer (1 mL/kg body weight) + 1 mL distilled water/kg/day; (2) STZ 40 mg/kg + 1 mL distilled water/kg/day; (3) STZ 40 mg/kg + ethyl acetate fraction of seed of <i>E. jambolana</i> (200 mg/2 mL distilled water/kg/day); (4) STZ 40 mg/kg + glibenclamide (20 mg/kg/day).	Antidiabetic effect: was observed an <sup>10</sup> insulinotropic activity, inhibition of intestinal glucose loading, and the degeneration of DNA of pancreatic beta-cells. Groups 3 and 4 showed the same behavior for serum levels of insulin and glycated hemoglobin, in addition to significantly reducing fasting glucose in the short and long term.
		8 days; 5 groups (n = 6): (1) control – only vehicle; (2) positive control – only vehicle + scopolamine (1 mg/kg, i.p.) – induced amnesia; (3) Standard drug - piracetam (200 mg/kg, i.p.) + scopolamine; (4) Methanolic extract of <i>S. cumini</i> (200 mg/kg, p.o.) + scopolamine; (5) Methanolic extract of <i>S. cumini</i> (400 mg/kg, p.o) + scopolamine.	Antiamnesic activity: improved cognitive deficit, decreased the time required for a successful labyrinth test, ameliorated the memory impairment, improves the response to oxidative stress, inhibits acetylcholinesterase activity. Thus, it is comparable to the effect of piracetam. Dose-dependency: better results with higher dosage. <sup>11</sup>

Results are expressed as mean  $\pm$  SD. References:<sup>1</sup> Raza et al. (2017); <sup>2</sup> Rekha et al. (2008); <sup>3</sup> Tanwar et al. (2011); <sup>4</sup>Tanwar et al. (2017); <sup>5</sup> Sharma et al. (2006); <sup>6</sup>Das & Sarma (2009); <sup>7</sup> Nahid et al. (2017); <sup>8</sup>Sharma et al. (2017); <sup>9</sup> Sharafeldin & Rizvi (2015); <sup>10</sup> Jana et al. (2015); <sup>11</sup> Alikatte et al. (2012).

## 1. Conclusion

The fruit of *S. cumini* is a great source of anthocyanins, mainly delphinidin, petunidin, malvidin and peonidin, which have a recognized antioxidant action. However, the levels of these compounds vary mainly according to the ripening stage of the fruit, intensifying over time. The fruit has other phenolic compounds, mainly galloyl glucose, gallic acid and hexahydroxydiphenoyl. In this way, the fruit can be a promising source of bioactive compounds, and thus improve human nutrition and access to compounds with a hypoglycemic, hypolipidemic, hepatoprotective, antioxidant, and anti-amnesic function.

Few studies were found regarding the carotenoid profile of the fruit, so further studies are suggested. Nevertheless, this work was the first to propose a possible pathway for carotenoid biosynthesis in *S. cumini* with the available data.

Studies show that *S. cumini* supplementation can help control blood glucose, improve lipid profile, and increase levels of antioxidant enzymes. However, human trials are recommended to clarify its actions and mechanisms on promoting health benefits, bioaccessibility and bioavailability of the phytochemicals.

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## Author disclosure statement

No competing financial interests exist.

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## **Artigo 3**

### **Bioactive Compounds of Jaboticaba (*Plinia* sp.): A Systematic Review**

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# Bioactive Compounds of Jaboticaba (*Plinia* sp.): A Systematic Review

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## ABSTRACT

A systematic review about nutrients and bioactive compounds of the *Plinia* sp. was carried out in the Science Direct, MEDLINE (via PubMed), and Capes Periodicals databases. After a complete reading of the selected articles and application of the inclusion and exclusion factors, 58 articles were selected. The whole jaboticaba fruit stood out for its high levels of total polyphenols, mainly anthocyanins (cyanidin and delphinidin), ellagic acid, methylellagic acid, gallic acid, myricetin, quercetin, castalagin, pedunculagin and vescalagin. When evaluating the behavior of these compounds after *in vitro* digestion, it is observed that anthocyanins did not suffer as much in the salivary and gastric stages, but showed a significant reduction after the intestinal stage. However, a significant reduction in hydrolysable tannins was reported, but the hydrolysis of these compounds reflected an increase in gallic and ellagic acids contents. *Plinia*

sp. presents moderate levels of carotenoids, but, only lutein and β-carotene are found. In addition, no studies were identified that evaluated the bioavailability of these compounds in this food matrix. Thus, further studies are suggested.

**Keywords:** Bioaccessibility; Carotenoids; Functional food; Myrtaceae family; Phenolic compounds; Physicochemical; Tropical food.

## 1 INTRODUCTION

The jaboticaba (*Plinia* sp.), a plant native to Brazil, belonging to the Myrtaceae Juss., is found in several regions of the country (North, Northeast, Central-West, Southeast, South, Northeast and Southeast), and, consequently, different phytogeographic domains (Amazon, Caatinga, Cerrado and Atlantic Forest) (Stadnik et al., 2020).

This genus has 42 cataloged species, 36 of which are endemic and 20 synonyms. Are they: *Plinia ambivalens* M. Souza & Sobral; *Plinia anonyma* Sobral; *Plinia callosa* Sobral; *Plinia clausa* Mc.Vaugh; *Plinia cordifolia* (D.Legrand) Sobral; *Plinia coronata* (Mattos) Mattos; *Plinia delicata* Antunes et al.; *Plinia edulis* (Vell.) Sobral; *Plinia espinhacensis* Sobral; *Plinia grandifolia* (Mattos) Sobral; *Plinia hatschbachii* (Mattos) Sobral; *Plinia humaitana* M.A.D.Souza & Sobral; *Plinia inflata* McVaugh; *Plinia involucrata* (O.Berg) McVaugh; *Plinia langsdorffii* (O.Berg) Sobral & M.C.Souza; *Plinia longa* Sobral & M.C.Souza; *Plinia longiacuminata* Sobral; *Plinia marqueteana* G.M.Barroso; *Plinia martinellii* G.M.Barroso & M.Peron; *Plinia muricata* Sobral; *Plinia nana* Sobral; *Plinia oblongata* (Mattos) Mattos; *Plinia parvifolia* (O.Berg) Stadnik & Sobral; *Plinia peruviana* (Poir.) Govaerts; *Plinia phitrantha* (Kiaersk.) Sobral; *Plinia pinnata* L.; *Plinia povedae* Sánchez; *Plinia pseudodichasiantha* (Kiaersk.) G.M.Barroso ex Sobral; *Plinia pumila* (Gardner) M.C.Souza & Sobral; *Plinia rara* Sobral; *Plinia renatiana* G.M.Barroso & Peixoto; *Plinia*

*rivularis* (Cambess.) Rotman; *Plinia rogersiana* Mattos; *Plinia rufiflora* Sobral & M.A.D.Souza; *Plinia sebastianopolitana* G.M.Barroso; *Plinia sessiliflora* (O.Berg) Stadnik & Sobral; *Plinia silvestris* (Vellozo) Mazine & Sobral; *Plinia spiciflora* (Nees & Mart.) Sobral; *Plinia spiritosantensis* (Mattos) Mattos; *Plinia subavenia* Sobral; *Plinia tapuruquarana* M.A.D.Souza & Sobral; *Plinia ybotyrype* Stadnik (Stadnik et al., 2020).

Among this wide variety of species, three stand out the most studied: *P. trunciflora* (O. Berg) Kausel [synonym: *Plinia tapuruquarana* M.A.D. Souza & Sobral; or *P. tetrapétala* L.], *Plinia cauliflora* (DC.) Berg (Paulista) [synonym: *Plinia callosa* Sobral; *Myrtus cauliflora* Mart.; *Myrciaria cauliflora* (Mart.) O. Berg; *Myrtus jaboticaba* Vell.; *Plinia jaboticaba* (Vell.) Kausel; *Myrcia jaboticaba* (Vell.) Baill; *Myrciaria jaboticaba* (Vell.) O. Berg; and *Eugenia jaboticaba* (Vell.) Kiaersk], and *Plinia jaboticaba* (Vell.) Berg (Sabará) [*Plinia involucrata* (O.Berg) McVaugh; *Myrciaria involucrata* O. Berg; *Plinia jaboticaba* (Vell.) Kausel; *Myrciaria jaboticaba* (Vell.) O. Berg; *Myrcia jaboticaba* (Vell.) Baill.] (Citadin et al., 2010; Stadnik et al., 2020). For the purposes of this work, we chose to report the name of the species as mentioned in the original article.

The complete *P. trunciflora* chloroplast genome is 159,512 bp long, comprising inverted repeats of 26,414 bp and single copy regions of 88,097 bp (LSC) and 18,587 bp (SSC). When compared with other fruits of the family *Myrtaceae*, it is observed that *P. trunciflora*, *Eugenia uniflora* e *Acca sellowiana* form a cluster very close to *Syzygium cumini*, in this way they can easily be compared (Eguiluz et al., 2017).

The jaboticaba occurs mainly in the Atlantic Forest Biome and in the high-altitude sub-forests, bordering rivers (Suguino et al., 2012). It comes in the form of a tree or shrub, can reach between 10 and 15 meters in height, has a pyramidal shape, long and dense crown, and a smooth trunk with a diameter between 30 and 40 cm, where the berries sprout. The white flowers are pediceled and sessile, with an axillary or stem distribution, and a prolonged hypanthium above

the ovary, which persists after anthesis (Stadnik et al., 2020; Suguino et al., 2012). The fruits are globose berries, approximately 3 cm in diameter, persistent calyx, one to two seeds, eugenioid embryo, and flat convex cotyledons (Stadnik et al., 2020; Suguino et al., 2012).

Fruit maturation is characterized by visible changes in fruit color, pH and firmness, as well as an increase in total anthocyanins, soluble solids, sugars and in pectin activity (Becker et al., 2015; Nascimento et al., 2013; Zhang et al., 2018). Fruits are classified as fully ripe when they are intensely black. Seven days after reaching this stage, the fruits are completely wilted and often rotten. (Nascimento et al., 2013).

Compounds isolated from the fruit may have anti-inflammatory action, by reducing IL-6, MCP-1, TNF- $\alpha$ , NF- $\kappa$ B, inflammatory infiltrate, and COX-2. Furthermore, *in vitro* studies have reported that jaboticaba extract may have antiproliferative effect on colon cancer cell (HT29 and HCT116), in NCIH460 (lung carcinoma), MCF-7 (breast carcinoma), HepG2 (hepatocellular carcinoma) and HeLa (cervical carcinoma), and against leukemia (K-562) and prostate cancer cell (PC-3). The consumption of *M. cauliflora* extract may have hypotensive effects in hypertensive rats, and the intake of *M. jaboticaba* extract may increase HDL-C in rats fed with high-fat and high-fructose-diet (Schulz et al., 2020).

The fruit of *Plinia* sp. presents great commercial potential, being used for manufacturing jam, fermented drinks, vinegar and liqueurs. In addition, they are appreciated *in natura*, and applied in the pharmaceutical industry, because of their high content of bioactive compounds. The plant is widely exploited ornamenteally, because of its exuberant architecture and beauty during flowering and fruiting (Citadin et al., 2010; Suguino et al., 2012). Thus, knowledge about the fruit can contribute to the strengthening of the regional economy and promote the cultivation and exploitation of the product.

In this context, in recent years there has been a growth in the interest of the scientific community in researching bioactive compounds and their effects on human health, to know the

potential of native Brazilian fruit species and increasing their value. Thus, in this study we reviewed the literature regarding nutrients and bioactive compounds of the *Plinia* sp. fruit, aiming to provide information for further studies.

## 2 METHODS OF RESEARCH

This review was carried out according to the methodology described by BRAZIL (2012). Therefore, to describe the nutritional composition and bioactive compounds of jaboticaba, highlighting its nutrients and bioactive compounds, the following combined terms were used: "jabuticaba" OR "jaboticaba" OR "*Plinia cauliflora*" OR "*Myrciaria jaboticaba*" OR "*Myrciaria cauliflora*", being searched on title, abstract, author-specified keywords or subject matter. The indexing terms used are in the platforms MeSH (Medical Subject Headings) and Emtree. The search was carried out in the databases Science Direct, MEDLINE (via PubMed), and Capes Periodicals. Filters were not used in relation to study types or year. Thus, the search was carried out from the beginning of each database until December 28, 2021 (date of the last search for all databases) and did not impose restrictions on the language of publication. Only original articles were selected.

Were included articles that described the proximate composition; analyzed the macro and micronutrients; profile of phenolic compounds, carotenoids or volatile organic compounds; and determined the bioaccessibility of those compounds in whole fruit, peel, pulp or seed of any jaboticaba variety. Other eligible studies were included by searching the reference lists of included studies.

Were excluded studies that described only the antioxidant activity by *in vitro* methods (DPPH, FRAP, ABTS or ORAC) or only total levels of bioactive compounds; analyzed the by-products (wine, juice, cachaça, vinegar), leaf or bark; reported the application as pigment or coloring or the seedling formation; and carried out studies on encapsulation and production of

emulsion, biodisel or nanoparticles. In cases of studies with duplicate results, the most complete work was selected.

The articles were pre-selected by reading their titles and abstracts, taking into account the eligibility criteria and excluding duplicates. Then, the papers were read in full and used to write this review. Due to the large number of articles on the profile of phenolic compounds, only the most recent literature (last 5 years) was considered. Unless the article was fundamental to the discussion of the results. Other articles were excluded because they did not discriminate which part of the fruit was analyzed (seed, pulp or skin).

### **3 RESULTS**

#### ***3.1 Results of the search***

A total of 139 articles were found in Science Direct, 156 in MEDLINE (via Pubmed) and 188 in Capes Periodicals. However, 253 documents were selected for reading, after excluding repeated articles. Furthermore, after reading the documents completely and applying the inclusion and exclusion factors, a total of 58 articles were reported in this review.

#### ***3.2 Macronutrients and minerals composition***

Macronutrients (water, proteins, lipids and carbohydrates) are essential compounds for life, provide energy and have specific functions in the human organism. For this, they must be consumed in adequate proportions (Venn, 2020). When digested, these nutrients are degraded and generate several metabolites. Some of these metabolites can be toxic, but the human body has self-regulatory mechanisms that control the propagation of these by-products (Oliphant & Allen-Vercoe, 2019).

The whole fruit of jaboticaba stands out for its high moisture content (79.41 to 87.4 g.100 g<sup>-1</sup>). At the same time, fruits from the same family have similar moisture contents

(*Myrcianthes pungens*: 83.2 g.100 g<sup>-1</sup>; *Syzygium cumini*: 84.7 g.100 g<sup>-1</sup>) (Seraglio et al., 2018).

Furthermore, significant concentrations of total carbohydrates (76.5 to 94.8 g.100 g<sup>-1</sup>), insoluble fiber (7.9 to 17.0 g.100 g<sup>-1</sup>) and ash (2.3 to 3.82 g.100 g<sup>-1</sup>) are observed. The same was reported for the whole fruit of juçara (*Euterpe edulis*), a fruit of the Myrtaceae family, which stands out for its moisture content (51.9 g.100 g<sup>-1</sup>), carbohydrates (85.7 g.100 g<sup>-1</sup>) and total fiber (71.8 g.100 g<sup>-1</sup>) (Inada et al., 2015).

In addition, peel and pulp of jaboticaba stands out for significant levels of protein (peel: 1.1 to 8.5 g.100 g<sup>-1</sup>; pulp: 0.44 to 6.76 g.100 g<sup>-1</sup>). However, the juçara pulp has higher levels of lipids (46.6 g.100 g<sup>-1</sup>) and proteins (7.5 g.100 g<sup>-1</sup>) (Inada et al., 2015) than those found for jaboticaba (Inada et al., 2015).

The drying temperature of the fruits influences the macronutrient contents. Alves et al. (2014) recommended to dry jaboticaba skin at 30°C, since this temperature better preserves its nutrients (protein, ash and dietary fibers) at the expense of drying at higher temperatures or even the lyophilization process. However, at 30°C, the stabilization of the moisture content occurred after 64 hours, while at higher temperatures, 45 and 60°C, it occurred after 34 and 32 hours, respectively (Alves et al., 2014). Another factor that can influence nutrient levels is the region of cultivation, as climatic conditions and soil characteristics influenced it (Oliveira et al., 2003; Pereira et al., 2018).

The jaboticaba pulp has higher levels of total sugars (79.78 g.100<sup>-1</sup> g, d.w. – dry weight) and reducing sugars (64.71 g.100<sup>-1</sup> g, d.w.) to the detriment of the other parts of the fruit (peel and seed), standing out for the fructose concentrations (*P. jaboticaba*: 32.96; *P. cauliflora*: 38.25 g.100<sup>-1</sup> g, d.w.), glucose (*P. jaboticaba*: 26.40; *P. cauliflora*: 32.87 g.100<sup>-1</sup> g, d.w.) and sucrose (*P. jaboticaba*: 11.69; *P. cauliflora*: 9.87 g.100<sup>-1</sup> g, d.w.) (Lima et al., 2011a). Furthermore, the *P. cauliflora* peel has arabinogalactan, a heteropolysaccharide, rich in

galactose (67.21%), glucose (15.78%), arabinose (9.78%) and rhamnose (2.26%) (Miranda et al., 2020).

The levels of sugars and soluble pectin in *M. jaboticaba* fruits increase during the maturation stages, simultaneously with the decrease in acidity (Becker et al., 2015), since the fruit is climacteric (Vieites et al., 2011). Furthermore, the average pectin content in pulp is 618 mg.100 g<sup>-1</sup>, and the increase in the percentage of soluble pectin coincides with intense polygalacturonase activity (Becker et al., 2015; Vieites et al., 2011).

Micronutrients are needed in small concentrations, yet they play important roles in the human body (Shukla et al., 2009). Plant-based foods provide most of the vitamins and minerals. Thus, the nutritional health and well-being of human beings entirely depend on plant foods, either directly or indirectly (Dellapenna, 1999).

The whole jaboticaba fruit has significant concentrations of potassium, magnesium, copper, manganese and iron (Table 2). The fruit offers significant levels of these nutrients to human health (K: 47.1 to 75.9%; Mg: 22.2 to 38.9%; Cu: 21.7 to 48.7%; Mn: 18.0 to 34.2%; Fe: 12.0 to 37.3% of recommended daily intake – RDI – for an adult based on 100 g of whole fruit) IOM (Lima et al., 2011a). In addition, it has higher values of iron, potassium and magnesium than *Euterpe edulis*, a fruit of the Mirtaceae family (Inada et al., 2015). However, it has lower concentrations of potassium and calcium than *Myrcianthes pungens*, and of calcium and magnesium compared to *Syzygium cumini* (Seraglio et al., 2018).

**Table 1.**Proximate composition (g.100 g<sup>-1</sup>, dry weight) of jaboticaba.

Reference	Species and genus	Moisture	Protein	Lipids	Ashes	Dietary fibers		Carbohydrates
						Soluble	Insoluble	
<i>Whole fruit</i>								
Inada et al. (2015) <sup>1</sup>	<i>M. jaboticaba</i>	87.40	5.00	1.80	3.10		38.2 <sup>2</sup>	90.10
Alezandro et al. (2013)	<i>M. jaboticaba</i>	82.00	0.94	0.40	2.90	2.30	17.00	76.50
Lima et al. (2008)	<i>M. jaboticaba</i>	79.41	0.92	0.42	3.82	2.23	16.63	-
Gurak et al. (2014)	<i>M. cauliflora</i>	-	0.95	0.65	3.60	3.41	7.90	94.80
Alezandro et al. (2013)	<i>M. cauliflora</i>	-	1.02	0.55	2.30	1.80	16.10	78.20
Lima et al. (2008)	<i>M. cauliflora</i>	80.35	0.88	0.44	2.75	3.57	14.27	-
<i>Peel (epicarp)</i>								
Miranda et al. (2020) <sup>1</sup>	<i>P. cauliflora</i>	74.8	17.86	5.16	9.92	-	-	75.00
Dallabona et al. (2020) <sup>1</sup>	<i>P. cauliflora</i>	4.59	3.60	1.20	2.72		20.89 <sup>2</sup>	92.12
Barros et al. (2019)	<i>P. cauliflora</i>	-	7.66	1.85	2.06	-	-	92.61
Calloni et al. (2015)	<i>P. trunciflora</i>	75.18	4.03	1.01	2.34	-	-	46.49
Alves et al. (2014)	<i>P. jaboticaba</i>	-	6.39	0.60	3.09	8.43	29.50	-
Batista et al. (2017)	<i>M. jaboticaba</i>	14.45	8.04	3.48	3.52	9.92	29.62	-
Inada et al. (2015) <sup>1</sup>	<i>M. jaboticaba</i>	80.90	8.50	0.60	4.00		38.40 <sup>2</sup>	93.10
Lenquiste et al. (2015)	<i>M. jaboticaba</i>	-	8.49	3.15	4.46	28.97	9.15	39.43
Lenquiste et al. (2012) <sup>1</sup>	<i>M. jaboticaba</i>	-	5.78	2.03	4.16	5.91	23.62	58.42
Leite-Legatti et al. (2012) <sup>1</sup>	<i>M. jaboticaba</i>	-	5.78	2.03	4.16	5.91	23.62	-
Leite et al. (2011) <sup>1</sup>	<i>M. jaboticaba</i>	-	5.05	1.64	3.89		8.35 <sup>2</sup>	-
Lima et al. (2008)	<i>M. jaboticaba</i>	84.24	1.16	0.57	4.40	6.80	26.43	-
Gurak et al. (2014)	<i>M. cauliflora</i>	-	1.14	0.98	3.71	12.64	7.70	94.16
Araújo et al. (2014) <sup>1</sup>	<i>M. cauliflora</i>	-	1.47	0.88	4.98		29.55 <sup>2</sup>	60.33
Lima et al. (2008)	<i>M. cauliflora</i>	75.84	1.10	0.68	2.88		6.77	27.03
<i>Pulp (mesocarp)</i>								
Miranda et al. (2020) <sup>1</sup>	<i>P. cauliflora</i>	84.10	2.52	1.26	1.89	-	-	94.97
Calloni et al. (2015)	<i>P. trunciflora</i>	86.46	1.55	1.25	1.70	-	-	96.82
Quatrin et al. (2018)	<i>M. jaboticaba</i>	-	6.76	1.57	3.98	11.22	18.21	58.26
Inada et al. (2015) <sup>1</sup>	<i>M. jaboticaba</i>	90.70	3.50	0.20	3.20		0.002	93.10
Lima et al. (2008)	<i>M. jaboticaba</i>	84.95	0.47	0.06	2.71		1.93	3.30
Sato & Cunha (2007)	<i>M. jaboticaba</i>	85.51	2.28	0.97	2.35	-	-	-
Lima et al. (2008)	<i>M. cauliflora</i>	83.91	0.44	0.21	2.90	1.77	2.57	-
<i>Seed</i>								
Inada et al. (2015) <sup>1</sup>	<i>M. jaboticaba</i>	58.00	7.10	0.60	2.40		31.80 <sup>2</sup>	89.80
Lima et al. (2008)	<i>M. jaboticaba</i>	71.48	1.17	0.58	2.68		1.40	26.93
Lima et al. (2008)	<i>M. cauliflora</i>	70.43	1.12	0.53	2.84	0.57	27.16	-

Results are expressed as mean ± standard deviation. <sup>1</sup>Dry weight values calculated using original data. <sup>2</sup> Total dietary fiber.

**Table 2.**Mineral composition (mg.100 g<sup>-1</sup>, dry weight) of jaboticaba.

Reference <sup>1</sup>	Species and genus	P	K	Ca	Mg	Na	S	Cu	Fe	Mn	Zn	N	B	Ni	Co <sup>2</sup>	Se <sup>2</sup>	Cd <sup>2</sup>
<i>Whole fruit</i>																	
Inada et al. (2015)	<i>M. jaboticaba</i>	75.7	700.0	27.1	72.3	23.3	31.0	0.8	23.7	1.1	1.1	-	-	2.8	30.0	1.9	1.0
Alezandro et al. (2013)	<i>M. jaboticaba</i>	100.0	1320.0	20.0	100.0	1.0	70.0	1.0	2.7	2.7	2.9	660.0	0.8	-	-	-	-
Lima et al. (2011a)	<i>M. jaboticaba</i>	76.7	1180.0	56.7	100.0	61.1	-	0.9	2.6	1.3	-	-	-	-	-	-	-
Alezandro et al. (2013)	<i>M. cauliflora</i>	110.0	1000.0	20.0	120.0	0.8	80.0	1.0	2.9	1.8	2.0	800.0	0.7	-	-	-	-
Lima et al. (2011a)	<i>M. cauliflora</i>	73.3	1113.3	60.0	86.67	60.8	-	0.9	5.9	1.3	-	-	-	-	-	-	-
<i>Peel</i>																	
Inada et al. (2015)	<i>M. jaboticaba</i>	89.0	1006.0	51.0	65.4	60.7	66.9	0.6	3.6	1.0	1.3	-	-	0.2	2.7	1.2	1.2
Lima et al. (2011a)	<i>M. jaboticaba</i>	63.3	1496.7	56.7	90.0	61.1	-	0.9	1.7	1.7	-	-	-	-	-	-	-
Lima et al. (2011a)	<i>M. cauliflora</i>	63.3	1206.7	50.0	80.0	62.2	-	0.9	1.8	1.7	-	-	-	-	-	-	-
<i>Pulp</i>																	
Inada et al. (2015)	<i>M. jaboticaba</i>	176.6	1978.5	67.4	187.9	153.6	57.1	1.8	32.8	2.3	3.1	-	-	3.9	37.2	3.4	2.5
Lima et al. (2011a)	<i>M. jaboticaba</i>	56.8	1026.7	53.3	73.3	62.5	-	0.7	0.0	1.2	-	-	-	-	-	-	-
Oliveira et al. (2003) <sup>3,4</sup>	<i>M. jaboticaba</i>	82.0	2795.5	1540.6	1227.9	-	58.4	418.1	21982.1	98.3	2880.6	-	-	-	-	-	-
Lima et al. (2011a)	<i>M. cauliflora</i>	53.3	1003.3	43.3	66.7	63.3	-	0.7	-	1.1	-	-	-	-	-	-	-
<i>Pulp and Peel</i>																	
Seraglio et al. (2018)	<i>M. cauliflora</i>	-	4533.8	330.1	455.6	359.8	-	-	-	-	-	-	-	-	-	-	-
<i>Seed</i>																	
Inada et al. (2015)	<i>M. jaboticaba</i>	95.1	401.2	17.1	51.3	38.3	35.1	0.5	1.3	0.4	0.8	-	-	0.1	0.9	1.2	0.9
Lima et al. (2011a)	<i>M. jaboticaba</i>	110.0	930.0	56.7	116.7	62.2	-	1.5	5.2	1.0	-	-	-	-	-	-	-
Lima et al. (2011a)	<i>M. cauliflora</i>	106.7	1006.7	70.0	110.0	54.2	-	1.2	3.8	0.9	-	-	-	-	-	-	-

<sup>1</sup>Results are expressed as mean. <sup>2</sup>µg.100 g<sup>-1</sup>.<sup>3</sup>Values presented for fruits collected in 10 locations in São Paulo, Brazil. <sup>4</sup>Original values transformed to dry basis.

### **3.3 Bioactive compounds of jaboticaba**

#### **3.3.1 Perfil of phenolic compounds**

Phenolic compounds have one or more hydroxyl groups attached to an aromatic ring, commonly found as esters or glycosides (Vermerris & Nicholson, 2006). These compounds come from the secondary metabolism of plants, which arise from the shikimate/phenylpropanoid pathway, producing phenylpropanoids, or the “polyketide” acetate/malonate pathway, which produce monomeric, polymeric and polyphenolic phenolics (Lattanzio, 2013). Based on the number of carbons, they can be classified into simple phenolics, phenolic acids, phenolic acids and related compounds, acetophenones and phenylacetic acids, cinnamic acids, cinnamyl aldehydes, cinnamyl alcohols, coumarins, isocoumarins, and chromones, chalcones, aurones, dihydrochalcones flavans, flavones, flavanones, flavanonols, anthocyanidins, anthocyanins, biflavonyls, benzophenones, xanthones, stilbenes, quinones, betacyanins, lignans, neolignans dimers or oligomers, lignin polymers, tannins oligomers or polymers, and polymers (Vermerris & Nicholson, 2006).

The accumulation of phenolic compounds in plant tissues is an adaptive response of plants to environmental conditions, varying according to evolution. Phenolics play a fundamental defense role against environmental stress, especially against the effect of light, temperature variations, pathogens, nutrient deficiencies and free radicals (Lattanzio, 2013; Marchiosi et al., 2020). Biotic and abiotic stress stimulate carbon flows from primary to secondary metabolic pathways, inducing changes in available resources in favor of the synthesis of these secondary products (Lattanzio, 2013). The major factors that limit the action of phenolic acids in the environment are their high biodegradability and strong adsorption by soil particles (Marchiosi et al., 2020).

**Table 3.**

Phenolic compounds identified in jaboticaba.

Phenolic compounds	Brito et al. (2021) <i>P. cauliflora</i> Peel	Castangia et al. (2021) <i>M. jaboticaba</i> Peel	Mannino et al. (2020) <i>P. trunciflora</i> Whole fruit	Palozi et al. (2020) <i>P. cauliflora</i> Peel	Barros et al. (2019) <i>P. cauliflora</i> Peel	Biazotto et al. (2019) <i>P. cauliflora</i> Polpa e peel	Romão et al. (2019) <i>P. cauliflora</i> Peel	Silva-Maia et al. (2019) <i>P. jaboticaba</i> Peel	Lamas et al. (2018) <i>M. jaboticaba</i> Peel	Neves et al. (2018) <i>P. spp.</i> Peel
<i>Antocianinas</i>										
Cy 3-o-gly		X			X				X	
Cy hex				X			X			
Cy 3-rutinoside						X				
Dp 3-o-gly					X					
Dp hex		X						X		
<i>Phenolic acids and derivatives</i>										
EA	X			X	X		X		X	X
EA-hex				X			X			X
EA-acetyl rhm										X
EA-rhm	X									X
EA-pent		X		X	X		X		X	X
EA-galloyl pent							X			X
EA-O-deoxyhexosyl							X			
MeEA										X
MeEA-pent										X
MeEA-pent										X
MeEA-acetyl-rhmpr										X
MeEA-caprylyl-rhmpr										X
MeEA-rhmpr										X
MeEA-valeryl-rhmpr										X
MeEA-acetyl-rhmpr	X									
Ferulic acid										
Gallic acid	X			X			X		X	X
Gallic acid-hex						X				
B-glucogallin	X						X			
Syringic acid						X				
Chlorogenic acid							X			
Quinic acid							X			
<i>Flavonols, flavonoids and derivatives</i>										
(-)Epicatechina									X	
Kampherol-3-O-glucoside		X								
M			X						X	
M-3-O-rhm			X							
M-hex										X
M-galloyl-hex						X				
M-rhm					X				X	X
Naringenin									X	
O-deoxyhexosyl M			X				X			
Quercimeritin								X		
Q						X			X	
Q-3-O-galactoside		X			X		X		X	X
Q-7-O-rhm		X								
Q-p-cm										X
Q-feruloyl										X
Q-hex			X		X					X
Q-pent			X			X				X
Q-rhm				X		X				X
Q-galloyl-pent										X
Q-glucuronide										X
Q-caprylyl-rhm										X
Q-di-O-galloylrhm						X				

	Brito et al. (2021) <i>P. cauliflora</i> Peel	Castangia et al. (2021) <i>M. jaboticaba</i> Peel	Mannino et al. (2020) <i>P. trunciflora</i> Whole fruit	Palozi et al. (2020) <i>P. cauliflora</i> Peel	Barros et al. (2019) <i>P. cauliflora</i> Peel	Biazotto et al. (2019) <i>P. cauliflora</i> Polpa e peel	Romão et al. (2019) <i>P. cauliflora</i> Peel	Silva-Maia et al. (2019) <i>P. jaboticaba</i> Peel	Lamas et al. (2018) <i>M. jaboticaba</i> Peel	Neves et al. (2018) <i>P. spp.</i> Peel
Q-valeryl-rhm				X				X		X
O-deoxyhexosyl Q										
Q iso				X		X				
Quercitrin								X		
Isoquercetin										
Rutin									X	
Syringin										
Syringin -2-Glc										
Valoneic acid										
Phloretin-dihex							X			
isorhamnetin						X				
<i>Tannins and Other compounds</i>										
HHDP-galloyl-glu	X									X
HHDP-galloylglu isos	X						X			
HHDP-galloyl-hex		X					X			X
HHDP-digalloyl-glu										X
HHDP trigalloyl-glu										
HHDP trigalloyl-hex							X			X
Bis-HHDP-glu					X					X
Bis-HHDP-hex		X								
Di-HHDP-galloyl-glu				X				X		
Di-HHDP-galloyl hex										
Di-HHDP-galloyl iso								X		
Di-O-galloyl-hex		X					X			
Tri-O-galloyl-hex		X					X			
Galloyl-bis-HHDP-glu			X							X
Galloyl-bis-HHDP-hex		X								
Castalagin/Vescalagin		X								
Casuarin										
Kaempferol-hex									X	
Pedunculagin						X			X	
Pentagalloyl-hex		X								X
Pterocarinin										
Sanguinin H-6		X								
Tellimagrandini	X									
Trigalloylglu	X					X				
Maclurin mono-O-galloyl-hex							X			
Maclurin-di-O-galloylhex						X				
O-cinnamoyl O-galloyl hex								X		

Dp: delphinidin; Cy: cyanidin; EA: ellagic acid; Me-EA: methylellagic acid; M: myricetin; Q: quercetin; glu: glucose; gly: glycoside; hex: hexoside; pent: pentoside; rhm: rhamnoside; rhmpyr: rhamnopyranoside; cm: coumaroyl; HHDP: Hexahydroxydiphenoyl; DHB: Dihydroxybenzoic; iso: isomer.

**Table 4.**Phenolic compounds ( $\text{mg.100 g}^{-1}$ , d. w.) quantified in jaboticaba.

Phenolic compounds	Senes et al. (2021) <sup>2</sup>		Neves et al. (2021)			Inada et al. (2020b)	Albuquerque et al. (2020) <sup>2</sup>	Quatrin et al. (2019)		Betta et al. (2018) <sup>2</sup>	Seraglio et al. (2018) <sup>2</sup>	Pereira et al. (2017) <sup>2</sup>		
	<i>M. cauliflora</i>	<i>M. cauliflora</i>	<i>M. jaboticaba</i>	<i>P. trunciflora</i>	<i>M. cauliflora</i>	<i>M. cauliflora</i>	<i>M. jaboticaba</i>	<i>M. trunciflora</i>	<i>M. jaboticaba</i>	<i>M. cauliflora</i>	<i>M. jaboticaba</i>	<i>M. cauliflora</i>	<i>M. jaboticaba</i>	<i>M. cauliflora</i>
	Pulp and seed	Peel	Peel	Peel	Peel and seed	Peel	Peel	Peel powder	Peel powder	Not described	Peel	Peel	Seed	Pulp
<i>Anthocyanins</i>														
Cy-3-gly	-	75.1 ± 1.8	80.6 ± 0.9	81.7 ± 1.0	725 ± 22	1945		1632 ± 69.1	1039 ± 47.1	-	-	270	-	-
Cy-3-glu-cm-gly	-	0.0 ± 0.0	0.2 ± 0.0	0.0 ± 0.1	-	-		-	-	-	-	-	-	-
Dp-3-gly	-	23.7 ± 2.1	18.5 ± 0.9	7.7 ± 1.1	73 ± 3	509		176 ± 7.5	108.1 ± 3.7	-	-	61.6	-	16.4
Pelargonidin-3-gly	-	0.6 ± 0.3	0.3 ± 0.1	0.3 ± 0.1	-	-		4.7 ± 0.2	1.9 ± 0.03	-	-	-	-	-
Peonidin-3-gly	-	0.5 ± 0.1	0.4 ± 0.1	0.2 ± 0.1	-	-		-	3.5 ± 0.1	-	-	-	-	-
<i>Phenolic acid</i>														
Benzoic acid	-	-	-	-	-	-		-	-	0.6	-	-	-	-
3,4-DHB acid	-	-	-	-	-	-		-	-	1.30	-	-	-	-
Caffeic acid	-	-	-	-	-	-		-	-	0.03	-	-	-	-
Chlorogenic acid	-	-	-	-	-	-		-	-	2.05	0.19	-	-	-
EA	56.00	66.1 <sup>1</sup>	73.4 <sup>1</sup>	62.3 <sup>1</sup>	229 ± 12	-		108.5 <sup>1</sup>	89.3 <sup>1</sup>	-	-	18.4	5.82	8.3
EA-hex	-	4.0 ± 0.9	6.9 ± 1.1	6.4 ± 1.5	-	-		-	-	-	-	-	-	-
EA-pent	-	7.5 <sup>1</sup>	8.8 <sup>1</sup>	25.0 <sup>1</sup>	-	-		-	19.0 <sup>1</sup>	-	-	-	-	-
EA-rhm	-	18.4 <sup>1</sup>	4.3 <sup>1</sup>	2.0 <sup>1</sup>	-	-		-	-	-	-	-	-	-
EA-acetyl-rhm	-	4.5 <sup>1</sup>	3.7 <sup>1</sup>	2.2 <sup>1</sup>	-	-		-	-	-	-	-	-	-
EA-valeryl-M	-	0.8 <sup>1</sup>	1.4 <sup>1</sup>	1.4 <sup>1</sup>	-	-		-	-	-	-	-	-	-
EA-caprylyl-M	-	0.4 ± 0.0	1.0 ± 0.1	1.5 ± 0.2	-	-		-	-	-	-	-	-	-
EA-galloyl-pent	-	-	1.5 ± 1.2	-	-	-		-	-	-	-	-	-	-
Me-EA-pent	-	-	-	28.4 ± 4.9	-	-		-	-	-	-	-	-	-
Me-EA-acetyl-rhmpyr	-	22.3 <sup>1</sup>	35.8 ± 2.4	0.0 ± 0.0	-	-		-	-	-	-	-	-	-
Me-EA caprylyl-rhmpyr	-	19.4 ± 0.3	32.4 ± 0.8	17.4 ± 1.7	-	-		-	-	-	-	-	-	-
Me-EA valeryl-rhmpyr	-	38.8 <sup>1</sup>	31.8 ± 1.7	36.6 <sup>1</sup>	-	-		-	-	-	-	-	-	-
Ferulic acid	-	-	-	-	-	-		-	-	0.20	-	-	-	-
Gallic acid	0.61	20.2 ± 6.4	17.0 ± 0.6	6.5 ± 1.6	127 ± 4	-		9.3 <sup>1</sup>	40.7 <sup>1</sup>	2.55	4.16	4.9	23.6	3.5
p-Coumaric acid	0.01	-	-	-	-	-		-	-	0.36	-	-	-	-
Protocatechuic acid	-	-	-	-	-	-		12.4 <sup>1</sup>	34.4 <sup>1</sup>	-	-	-	-	-
Syringic acid	-	-	-	-	-	-		-	-	0.10	-	-	-	-
<i>Flavonols, Flavonoids and derivatives</i>														
(+)-Catechin	3.62	-	0.8 ± 0.0	-	-	-		-	-	1.39	-	-	-	-
Catechin or Epicatechin +	-	-	-	-	-	-		37.8 ± 6.4	5.6 ± 0.5	-	-	-	-	-
Castalin isomer	-	-	-	-	-	-		-	-	0.16	-	-	-	-
(-)-Epigallocatechin gallate	-	-	-	-	-	-		-	-	4.33	0.864	-	-	-
Isoquercitrin	-	-	-	-	-	-		-	-	0.18	0.08	-	-	-
Isorhamnetin	-	-	-	-	-	-		-	-	0.03	-	-	-	-
Kaempferol	-	-	-	-	-	-		-	-	0.01	-	-	-	-
Luteolin	-	-	-	-	-	-		-	-	-	-	-	-	-
M	-	-	-	-	1.2 ± 0.0	-		-	-	-	-	-	-	-
M-hex	-	12.7 ± 2.5	9.3 ± 0.5	8.0 ± 0.9	-	-		-	-	-	-	-	-	-
M-hex	-	7.0 ± 2.8	5.1 ± 4.0	10.1 ± 5.2	-	-		-	-	-	-	-	-	-
M-rhm	-	80.2 ± 5.3	85.6 ± 3.6	81.9 ± 5.5	7.7 ± 0.3	-		59.4 ± 4.1	53.9 ± 1.9	-	-	-	-	-
Naringenin	0.01	-	-	-	-	-		-	-	0.04	0.04	-	-	-
Pinobanksin	-	-	-	-	-	-		-	-	0.05	0.41	-	-	-

Phenolic compounds	Senes et al. (2021) <sup>2</sup> <i>M. cauliflora</i> Pulp and seed	Neves et al. (2021)			Inada et al. (2020b) <i>M. cauliflora</i> Peel and seed	Albuquerque et al. (2020) <sup>2</sup> <i>M. jaboticaba</i> Peel	Quatrin et al. (2019)		Betta et al. (2018) <sup>2</sup> <i>M. cauliflora</i> Not described	Seraglio et al. (2018) <sup>2</sup> <i>M. jaboticaba</i> Peel	Pereira et al. (2017) <sup>2</sup>			
		<i>M. cauliflora</i> Peel	<i>M. jaboticaba</i> Peel	<i>P. trunciflora</i> Peel			<i>M. trunciflora</i> Peel powder	<i>M. jaboticaba</i> Peel powder			<i>M. cauliflora</i> Peel	<i>M. jaboticaba</i> Peel	<i>M. cauliflora</i> Seed	<i>M. cauliflora</i> Pulp
		-	3.3 ± 0.1	3.1 ± 3.0	3.9 ± 0.9	1.1 ± 0.1	-	-	1.16	5.21	-	-	-	-
Q-caffeoic acid hex	-	0.7 ± 0.3	1.0 ± 0.3	1.4 ± 0.1	-	-	-	-	-	-	-	-	-	-
Q-cm-hex	-	2.9 <sup>1</sup>	3.3 <sup>1</sup>	3.0 <sup>1</sup>	-	-	-	-	-	-	-	-	-	-
Q-feruloyl-hex	-	2.1 <sup>1</sup>	2.9 <sup>1</sup>	3.5 <sup>1</sup>	-	-	-	-	-	-	-	-	-	-
Q-hex	-	15.1 <sup>1</sup>	39.6 <sup>1</sup>	37.9 <sup>1</sup>	-	-	38.3 <sup>1</sup>	25.8 <sup>1</sup>	-	-	-	-	-	-
Q-galloyl-pent	-	1.4 <sup>1</sup>	1.1 ± 0.5	0.0 ± 0.0	-	-	-	-	-	-	-	-	-	-
Q-pent	-	23.4 <sup>1</sup>	22.1 <sup>1</sup>	14.1 <sup>1</sup>	-	-	26.5 <sup>1</sup>	-	-	-	-	-	-	-
Q-rhm	-	26.6 ± 2.8	26.9 ± 11.7	35.9 ± 2.9	117 ± 6	5.1	25.4 ± 1.2	18.9 ± 0.4	-	-	-	-	-	-
<i>Tannins and other compounds</i>														
Casuarinin + HHDP-galloylglu	-	-	-	-	-	-	89.6 ± 4.1	18.1 ± 1.0	-	-	-	-	-	-
Casuarin + HHDP-galloylglu + 3-O-galloylquinic acid	-	-	-	-	-	-	168 ± 21	45.7 ± 3.6	-	-	-	-	-	-
Castalagin/Vescalagin	-	-	-	-	-	42.3	60.8 ± 6.1	15.3 ± 0.3	-	-	-	-	-	-
Castalagin	-	90.8±7.1	61.6±4.1	57.5±5.8	-	-	-	-	-	-	-	-	1756.7	77.0
Cauliflorin	-	-	-	-	-	-	-	-	-	-	-	21.2	-	16.4
Bis-HHDP-galloyl-glu iso	-	-	-	-	-	20.5	-	15.7 ± 1.0	-	-	-	-	-	-
Bis-HHDP-glu (Casuarin)	-	-	-	-	-	-	-	-	-	-	-	-	-	-
HHDP-galloyl-glu	-	-	-	-	-	9.3	14.5 ± 4.1	3.1 ± 0.3	-	-	-	-	-	-
HHDP-digalloylglu iso +	-	-	-	-	-	-	115 ± 2	14.8 ± 0.8	-	-	-	-	-	-
Trisgalloyl-HHDP-glu iso	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Galloyl-bis-HHDP-glu (Casuarinin)	-	-	-	-	-	7.5	-	-	-	-	-	-	-	-
Galloyl-castalagin +	-	-	-	-	-	-	142 ± 12	89.0 ± 3.7	-	-	-	-	-	-
Pentagalloyl glu	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Galloyl-castalagin iso	-	-	-	-	-	-	44.9 ± 4.8	17.4 ± 1.0	-	-	-	-	-	-
Mono-galloyl-glu + HHDP-galloyl-glu	-	-	-	-	-	-	9.9 ± 4.5	3.7 ± 0.8	-	-	-	-	-	-
Di-galloyl-glu + Casuarictin	-	-	-	-	-	-	127 ± 6	33.4 ± 1.7	-	-	-	-	-	-
Di-galloyl-hex	-	-	-	-	-	23.2	-	-	-	-	-	-	-	-
Tri-galloyl-glu	-	-	-	-	-	140.8	217 ± 2	18.8 ± 0.7	-	-	-	-	-	-
Tri-galloyl-glu iso	-	-	-	-	-	-	-	5.8 ± 0.4	-	-	-	-	-	-
Tris-galloyl-HHDP-glu iso	-	-	-	-	-	26.4	18.8 ± 1.3	11.2 ± 0.8	-	26.4 <sup>1</sup>	-	-	-	-
Tetra-galloyl-glu	-	-	-	-	-	-	40.9 ± 3.3	24.7 ± 2.4	-	-	-	-	-	-
Tetra-galloyl-glu iso	-	-	-	-	-	-	244 ± 18	71.8 ± 4.3	-	-	-	-	-	-
Penta-galloyl-glu	-	-	-	-	-	51.0	-	-	-	51.0	-	-	-	-
Tellimagrandin I + Castalin	-	-	-	-	-	-	91.4 ± 7.8	9.8 ± 1.0	-	-	-	-	-	-
Pedunculagin	-	-	-	-	-	-	93.0 ± 9.0	30.4 ± 3.4	-	12.6	22.3	117.5	23.9	-
Vescalagin	-	170.8±17.4	77.0±3.9	97.8±9.0	-	-	-	-	-	-	4.1	952.7	24.6	-

<sup>1</sup>Equal compounds that were identified at different peaks in the same survey were summed. <sup>2</sup>Values converted to mg/100 g.

Dp: delphinidin; Cy: cyanidin; EA: ellagic acid; Me-EA: methyllellagic acid; M: myricetin; Q: quercetin; glu: glucoside; gly: glycoside; hex: hexoside; pent: pentoside; rhm: rhamnoside; rhmpyr: rhamnopyranoside; cm: coumaroyl; HHDP: Hexahydroxydiphenyl; DHB: Dihydroxybenzoic; iso: isomer.

**Table 5.**Phenolic compounds ( $\text{mg.g}^{-1}$ , d. w.) quantified in extracts of jaboticaba.

Phenolic compounds	Castilho et al. (2021)	Albuquerque et al. (2020)	Fidelis et al. (2020)	Machado et al. (2018) <sup>2</sup>				Rodrigues et al. (2021) <sup>3</sup> <i>P. jaboticaba</i> Whole fruit Methanol/water/acetic acid	Moura et al. (2018) <sup>3</sup> <i>P. jaboticaba</i> Whole fruit Methanol/water/acetic acid SPE column		
	<i>M. jaboticaba</i> Peel	<i>M. jaboticaba</i> Peel	<i>M. jaboticaba</i> Seed	<i>P. jaboticaba</i> Peel							
	Hydroethanolic	Hydroethanolic	Hydroacetonic	Aqueous	Methanolic	Ethanolic	Acetone				
<i>Anthocyanins</i>											
Cyanidin	-	-	-	-	0.60	0.29	0.10	-	-		
Cyanidin 3-O-gly	12.34 ± 0.05	39.7 ± 0.1	-	-	-	-	-	880.28 ± 23.41	117 ± 1		
Cyanidin 3-rutinoside	-	-	-	-	-	-	-	-	190 ± 12		
Delphinidin	-	-	-	0.45	-	0.36	-	-	-		
Delphinidin 3-O-gly	1.63 ± 0.01	10.39 ± 0.04	-	-	-	-	-	239.75 ± 0.48	23 ± 1		
Malvidin	-	-	-	-	0.39	-	-	-	-		
Malvidin 3-O-gly	-	-	-	-	-	-	-	-	-		
<i>Phenolic acid and derivatives</i>											
2-Hydroxycinnamic acid	-	-	0.02	-	-	-	-	-	-		
Casuarin	-	-	-	-	-	-	-	3.16 ± 0.02	-		
Ellagic acid	1.58 ± 0.02	-	3.88	-	-	-	-	269.77 ± 5.50	-		
Ferulic acid	-	-	0.55	0.00	0.01	0.01	0.01	-	-		
Gallic acid	-	-	2.30	0.02	0.02	0.02	0.03	-	-		
O-coumaric acid	-	-	-	0.00	0.00	0.01	0.00	-	-		
p-coumaric acid	-	-	0.07	0.01	0.05	0.08	0.01	-	-		
Pedunculagin	-	-	-	-	-	-	-	83.81 ± 1.00	-		
Strictinin	-	-	-	-	-	-	-	48.00 ± 0.04	-		
Syringic acid	-	-	0.54	0.02	0.02	0.01	0.00	-	-		
Tellimagrandin I	-	-	-	-	-	-	-	21.25 ± 0.29	-		
<i>Flavonol and Flavonoid</i>											
Catechin	-	-	-	0.10	0.58	1.18	0.42	-	-		
Epicatechin	-	-	-	0.08	0.11	0.33	0.36	-	-		
Epicatechin gallate	-	-	-	0.29	0.01	0.85	0.00	-	-		
Myricetin 3-O-rhm	-	-	-	-	-	-	-	14.59 ± 0.35	27 ± 1		
Quercetin-3-O-rhm	0.218 ± 0.00	0.11 ± 0.01	-	-	-	-	-	8.57 ± 0.37	28 ± 1		
Quercetin-3-rhm	-	-	0.05	-	-	-	-	-	14.0 ± 0.1		
Procyanidin A2	-	-	4.51	-	-	-	-	-	19 ± 1		
<i>Tannins and Other compounds</i>											
Bis-HHDP-glu iso	2.85 ± 0.05	0.17 ± 0.01	-	-	-	-	-	-	-		
Bis-HHDP-glu iso	4.87 ± 0.06	0.262 ± 0.00	-	-	-	-	-	-	-		
Galloyl-HHDP-glu	-	0.19 ± 0.01	-	-	-	-	-	-	-		
Galloyl-bis-HHDP-glu iso	6.67 <sup>1</sup>	0.86 <sup>1</sup>	-	-	-	-	-	-	-		
Di-galloyl-HHDP-glu iso	4.1 ± 0.2	0.48 <sup>1</sup>	-	-	-	-	-	-	-		
Tri-galloyl-HHDP-glu	-	2.93 ± 0.01	-	-	-	-	-	-	-		
Penta-galloyl glu	5.99 <sup>1</sup>	1.06 ± 0.04	-	-	-	-	-	-	-		
Castalagin/vescalagin	2.22 ± 0.06	0.88 <sup>1</sup>	-	-	-	-	-	-	-		
Castalagin	-	-	133.49	-	-	-	-	-	-		
Vescalagin	-	-	68.75	-	-	-	-	-	-		

<sup>1</sup>Equal compounds that were identified at different peaks in the same survey were summed. <sup>2</sup>Values converted to mg/100 g. <sup>3</sup>µg/mL. glu: glucoside; gly: glycoside; hex: hexoside; pent: pentoside; rhm: rhamnoside; HHDP: Hexahydroxydiphenyl; iso: isomer.

Whole fruit of jaboticaba (*P. trunciflora*, *P. cauliflora*, *P. jaboticaba*, *P. phitrantha*) has significant levels of total phenolics (1196.5 to 2031.1 mg GAE.100 g<sup>-1</sup>), with peel being the part with the highest levels of these compounds (605.1 to 1149.9 mg GAE.100 g<sup>-1</sup>) (Neves et al., 2021). Together, the pulp and peel of *P. cauliflora* have levels of total phenolic compounds that stand out against other tropical fruits, such as araçá (*Psidium cattleianum*), mangaba (*Hancornia speciosa*), pequi (*Caryocar brasiliense*) and jenipapo (*Genipa americana*), but with levels are similar to those reported for cagaita (*Stenocalyx dysentericus*) and jatobá (*Hymenaea courbaril*) (Biazotto et al., 2019).

The total content of phenolic compounds of the whole fruit of *P. trunciflora* aqueous extract is  $1201.67 \pm 33.29$  mg GAE.100 g<sup>-1</sup>, while the total content of anthocyanins is  $175.33 \pm 11.80$  mg cyanidin 3-O-glucoside equivalents.100 g<sup>-1</sup> (Sacchet et al., 2015). However, a more recent study (Silva-Maia et al., 2019) described higher levels (2580 mg GAE.100 g<sup>-1</sup>) for total phenolics in aqueous extract of *P. jaboticaba*, reporting yellow flavonoids (303 mg Catechin Equivalents.100 g<sup>-1</sup>) and anthocyanins (150 mg Cyanindin-3-Glucoside Equivalents.100 g<sup>-1</sup>).

Jaboticaba (pulp and peel – deseeded fruit) has the lowest levels of phenolic compounds (dry weight; dw) among other fruits of the Myrtaceae family (*Myrciaria cauliflora*:  $31.6 \pm 0.39$  mg GAE.g<sup>-1</sup>, *M. vexator*:  $44.1 \pm 1.21$  mg GAE.g<sup>-1</sup>, *M. dubia*:  $101 \pm 0.25$  mg GAE.g<sup>-1</sup>); but higher than some fruits of the Eugenia family (*Eugenia aggregata*, *E. brasiliensis*, *E. luschnathiana*, *E. reinwardtiana*), which vary between 9.25 and 25.3 mg GAE.g<sup>-1</sup> (Reynertson et al., 2008). It stands out for its contents higher than five fruits of the Syzygium family (*S. cumini*, *S. jambos*, *S. javanicum*, *S. malaccense*, *S. samarangense*, and *S. samarangense*) analyzed by the same author, which varied between 3.57 and 23.8 mg GAE.g<sup>-1</sup>, except for *S. curranii* ( $39.6 \pm 0.77$  mg GAE.g<sup>-1</sup>) (Reynertson et al., 2008).

When compared with other exotic fruits, jaboticaba (*M. cauliflora*, 460.8 mg.100 g<sup>-1</sup>) has higher phenolic compounds than *Syzygium jambos* (190.4 mg.100 g<sup>-1</sup>), *Averrhoa carambola*

(382.8 mg.100 g<sup>-1</sup>), *Anacardium occidentale* (432.0 mg.100 g<sup>-1</sup>) and *Euphoria longana* (382.8 mg.100 g<sup>-1</sup>). However, it has lower levels than *Calocarpum mamosum* (1508.0 mg.100 g<sup>-1</sup>), *Manilkara zapota* (672.0 mg.100 g<sup>-1</sup>), *Pouteria caimito* (616.0 mg.100 g<sup>-1</sup>), *Malpighia emarginata* (616.0 mg.100 g<sup>-1</sup>), *Eugenia viniflora* (591.6 mg.100 g<sup>-1</sup>) (Assis et al., 2009).

The ripening of the fruit can negatively influence the concentration of total phenolics in the peel and pulp of *M. cauliflora*, reducing from 1530.16 ± 41.72 to 1443.63 ± 12.86 mg GAE.100 g<sup>-1</sup>, d.w., when changing from intermediate to mature stages (Seraglio et al., 2018). The same can be observed for *Myrcianthes pungens* (from 2061.35 ± 51.26 to 1739.28 ± 8.12 mg GAE.100 g<sup>-1</sup>, d.w.) and *Syzygium cumini* (from 1002.70 ± 11.65 to 957.72 ± 6.49 mg GAE.100 g<sup>-1</sup>, d.w.) (Seraglio et al., 2018). In contrast, Alezandro et al. (2013) observed that, despite showing a significant reduction in ellagic acid levels (stage 1: 9566±812; stage 2: 8327±129; stage 3: 636 3±629; stage 4: 6810±606; stage 5: 5050±99 mg.100 g<sup>-1</sup> of sample, d.w.), the content of total anthocyanins increases throughout the maturation process of *M. jaboticaba*, reporting a gradual increase over 5 stages of maturation (stage 1: 4.9±0.3; stage 2: 44±1; stage 3: 65±1; stage 4: 74±3; stage 5: 147±10 mg.100 g<sup>-1</sup> of sample, d.w.).

Flavoids are a class of low molecular weight phenolics that are widely distributed in angiosperms and are easily recognized as pigments present in flowers and fruits. These compounds are subdivided into different subgroups, depending on the carbon of the C ring on which the B ring is attached, and the unsaturation and oxidation of the C ring. Thus, they can be classified into anthocyanins, chalcones, flavanones, flavones, flavonols and isoflavonoids (Panche, Diwan, & Chandra, 2016). Among these, anthocyanins stand out, whose best known compounds are cyanidin, delphinidin, malvidin, pelargonidin and peonidin. Its nomenclature derives from the junction of two Greek words, “anthos = flower” and “kianos = blue” (Chen & Inbaraj, 2019).

These compounds are found in the outermost layers of fruits, presenting colors that vary between red, magenta, purple and blue in flowers, fruits and vegetables, according to methylation or acylation of hydroxyls in rings A and B or changes in pH. (Chen & Inbaraj, 2019; Panche, Diwan, & Chandra, 2016). Anthocyanins have been shown to display obvious anti-oxidative, anti-inflammatory, and anti-apoptotic activities (Zhang et al., 2019).

Thus, regarding the total anthocyanin content (d.w.), the concentration in the peel ( $15.85 \pm 0.74 \text{ mg.g}^{-1}$ ) of *M. cauliflora* stands out to the detriment of the other parts of the fruit (pulp:  $0.09 \pm 0.00 \text{ mg.g}^{-1}$ ; seed:  $0.35 \pm 0.02 \text{ mg.g}^{-1}$ ; whole fruit:  $5.83 \pm 0.68 \text{ mg.g}^{-1}$ ) and the same is observed for *M. jaboticaba* (peel:  $20.57 \pm 0.66 \text{ mg.g}^{-1}$ ; pulp:  $0.10 \pm 0.02 \text{ mg.g}^{-1}$ ; seed:  $0.31 \pm 0.02 \text{ mg.g}^{-1}$ ; whole fruit:  $8.37 \pm 0.72 \text{ mg.g}^{-1}$ ) (Lima et al., 2011b).

*M. jaboticaba* has total anthocyanin values (166.9 to 180.7 mg.100 g<sup>-1</sup>) higher than those of *S. malaccense* (51.0 to 70.3 mg.100 g<sup>-1</sup>), but lower than the levels reported for *S. cumini* pulp (124.1 to 231.0 mg.100 g<sup>-1</sup>). According to Frauches et al. (2021), Romualdo et al. (2021) and Peixoto et al. (2016), this is justified because *S. cumini* has a greater variety of compounds (cyanidin-3,5-O-diglucoside, delphinidin-3,5-O-diglucoside, petunidin-3,5-O-diglucoside and malvidin-3,5-O-diglucoside) than the other fruits. However, other studies (Neves et al., 2021; Quatrin et al., 2019) described pelargonidin and peonidin in jaboticaba (*M. cauliflora* and *M. jaboticaba*) peel.

In both varieties (*M. cauliflora*, *M. jaboticaba*), the fruit stands out for its cyanidin-3-O-glycoside contents (*M. cauliflora* - peel:  $25.82 \pm 1.14 \text{ mg.g}^{-1}$ ; pulp:  $0.18 \pm 0.04 \text{ mg.g}^{-1}$ ; *M. jaboticaba* - peel:  $25.98 \pm 2.78 \text{ mg.g}^{-1}$ ; pulp:  $0.07 \pm 0.00 \text{ mg.g}^{-1}$ ), but it also has delphinidin-3-O-glycoside in its composition (*M. cauliflora* - peel:  $3.09 \pm 0.26 \text{ mg.g}^{-1}$ ; pulp:  $0.00 \pm 0.01 \text{ mg.g}^{-1}$ ; *M. jaboticaba* - peel:  $2.71 \pm 0.29 \text{ mg.g}^{-1}$ ; pulp:  $0.00 \pm 0.00 \text{ mg.g}^{-1}$ ) (Lima et al., 2011b). Leite et al. (2011) observed similar results when analyzing *M. jaboticaba* peel (cyanidin 3-O-glycoside:  $19.64 \text{ mg.g}^{-1}$ , d.w.; delphinidin 3-O-glycoside:  $6.35 \text{ mg.g}^{-1}$ , d.w.).

This difference between the levels of cyanidin-3-O-glycoside (C3G) and delphinidin-3-O-glycoside (D3G), described before and observed in Tables 4 and 5, can be explained because the expression of F3'5' H (which is responsible for the synthesis of delphinidin) in mature jaboticaba to be lower than the expression of F3'H – which regulates the production of anthocyanins based on cyanidin –, since F3'H and F3'5'H are competitively regulated. It is important to note that mutations in cytochrome b5 (Cytb5) reduce F3'5'H activity, affecting delphinidin accumulation during ripening. In mature jaboticaba peel, the FPKM value of Cytb5 is 15 times higher than in green peel (Zhang et al., 2018).

Cyanidin stands out for having several effects on human health, including anti-inflammatory, anticancer, antidiabetic, antitoxic and cardio and neuroprotective capabilities (Liang et al., 2021). Anthocyanins, particularly cyanidin-3-O-glucoside, produce preventive and therapeutic activities in a wide range of neurodegenerative disorders, such as cerebral ischemia, Alzheimer's disease, Parkinson's disease, multiple sclerosis, and glioblastoma (Zhang et al., 2019).

Cyanidin-3-O-glycoside and its metabolites (ferulic acid, protocatechuic acid, phloroglucinaldehyde and vanillic acid) improve the microenvironment and attenuate oxidative stress and inflammation in enterocytes, improving intestinal integrity and function. These metabolites contribute to regulating the intestinal microbiota and affect the antioxidant system mediated by Nrf2 (nuclear factor (erythroid-derived 2)-like 2) and some inflammatory pathways, such as the MAPK (mitogen-activated protein kinase) pathway mediated by TAK1 (transforming growth factor β-activated kinase-1) and the NF-κB (nuclear factor-κB) pathway mediated by SphK/S1P (sphingosine kinases/sphingosine-1-phosphate) (Tan et al., 2019). Furthermore, Shan et al. (2021) concluded that cyanidin-3-glucoside can attenuate myocardial Ischemia-Reperfusion injury by inhibiting ferroptosis both in vivo and in vitro, thus preventing deubiquitination.

When comparing jaboticaba (*M. cauliflora*, pulp and peel) with other fruits of the Myrtaceae family, the fruit has cyanidins levels ( $4.33 \pm 0.24 \text{ mg.g}^{-1}$ , d. w.) higher than most of the other fruits analyzed (*E. aggregata*, *E. luschnathiana*, *E. reinwardtiana*, *M. dubia*, *S. cumini*, *S. jambos*, *S. javanicum*, *S. malaccense*, *S. samarangense* and *S. samarangense* var. *Taiwan pink*), being inferior only to the fruits of *E. brasiliensis* ( $10.2 \pm 0.42 \text{ mg.g}^{-1}$ , d. w.), *M. vexator* ( $13.1 \pm 3.17 \text{ mg.g}^{-1}$ , d. w.) and *S. curranii* ( $9.56 \pm 0.84 \text{ mg.g}^{-1}$ , d.w.) (Reynertson et al., 2008).

The profile of phenolic compounds in jaboticaba has been widely described in the literature, especially in the last five years (Table 3, 4 and 5). However, it is important to report the significant variation between the observed results, both regarding the identified compounds and the reported levels. Several factors hamper the comparison between the results: variation between the measurement units used in the expression of the results; lack of information about the moisture content of in natura or lyophilized samples; and expression in grams of extract or lyophilized powder, rather than grams of fruit. For this reason, it was created three different tables (Table 3, 4 and 5), to approach the largest number of studies and ease the comparison of similar results.

Thus, regarding the profile of non-anthocyanin phenolic compounds, the contents of ellagic acid, methylellagic acid, gallic acid, myricetin, quercetin, castalagin, pedunculagin and vescalagin stand out in jaboticaba (Table 4 and 5). Fruits of different varieties (*M. cauliflora*, *M. jaboticaba* and *P. trunciflora*) present phenolic profiles with minor variations (Neves et al., 2021). On the other hand, large variations can be observed between peel, pulp and seed of *M. cauliflora* (Pereira et al., 2017).

Jaboticaba (pulp and peel) has levels of ellagic acid ( $0.52 \pm 0.22 \text{ mg.g}^{-1}$ , d.w.) higher than most fruits of the family *Myrtaceae* (*E. aggregata*, *E. brasiliensis*, *E. luschnathiana*, *E. reinwardtiana*, *M. dubia*, *S. cumini*, *S. cumini*, *S. jambos*, *S. javanicum*, *S. malaccense*, *S.*

*samarangense* and *S. samarangense* var. *Taiwan pink*), being inferior to *M. vexator* ( $0.64 \pm 0.26 \text{ mg g}^{-1}$ , d. w.) (Reynertson et al., 2008).

Hydrolysable tannins, especially ellagitannins, which are often found in jaboticaba peels, include gallic acid and its derivatives and one or more units of hexahydroxydiphenolic acid (HHDP), linked to a sugar residue, characterizing, for example, the following compounds: casuariin, pedunculagin, strictinin, casuarinin, tellimagrandin I. However, they are not absorbed by the human body and must be hydrolyzed to form ellagic acid (Alfei et al., 2019).

Among the major functions of ellagic acid, its ability to improve the lipid profile stands out, besides its antioxidant and anti-inflammatory properties (modulation of tumor necrosis factor- $\alpha$ , interleukin-1 $\beta$  and interleukin-6, and reduction of the activity of nuclear factor- $\kappa B$  while increasing the expression of factor 2 related to erythroid nuclear factor 2) (Ríos et al., 2018). Thus, it has been described in the literature that these compounds may have potential benefits to human health, including anticancer (specific mechanisms that affect cell proliferation, apoptosis and DNA damage), antiatherogenic and neuroprotective activities (Alfei et al., 2019; Ríos et al., 2019; Ríos et al., 2018). Besides having effects on metabolic syndrome and diabetes, by demonstrating diverse functions in regulating insulin, glycogen, phosphatases and aldose reductase, sorbitol accumulation, formation of advanced glycation end products and resisting secretion (Ríos et al., 2018).

### 3.3.2 Bioaccessibility of phenolic compounds

Ellagic acid, for example, has low bioavailability because of several factors, like trivial water-solubility, first pass effect, and irreversible binding to cellular DNA and proteins (Alfei et al., 2019). Therefore, studies that evaluate the bioaccessibility of these compounds in different food matrices are of paramount importance.

Stafussa et al. (2021) reported that the bioaccessibility of the total phenolic content in 10 fruits vary between 8.36% and 14.39%. According to these authors, the levels of phenolics in *Myrciaria cauliflora* puree after gastric digestion is  $3133.00 \pm 404.47$  mg GAE.100 g<sup>-1</sup> (d.w.) and after intestinal digestion it reduces to  $744.17 \pm 152.97$  mg GAE.100 g<sup>-1</sup> (d.w.), showing 12.84% bioaccessibility. When comparing three different fruits of the Myrtaceae family, Peixoto et al. (2016) documented that the total content of bioaccessible anthocyanins in *M. jaboticaba* (13%) after gastric digestion is lower than in *Syzygium jambos* (45%) and *Syzygium cumini* (65%) and that these levels are even lower after intestinal digestion (*M. jaboticaba*: 10%; *Syzygium jambos*: 15%; *Syzygium cumini*: 45%).

When analyzing the bioaccessibility of phenolics in *M. jaboticaba* peel, Tarone et al. (2021) reported that only anthocyanins could be recovered after *in vitro* digestion, since the concentration of the other compounds presented values that were too low to be quantified. The researchers observed that the percentage of recovery of the compounds varied according to the dilution of anthocyanin extract employed in the analysis. Therefore, after the gastric phase, in the extract with the highest concentration of anthocyanins (5 mg in 1 mL of simulated gastric fluid - SGF) it was possible to recover 72% of the total content of cyanidin-3-O-glycoside (C3G) and 22% of delphinidin-3-O-glycoside (D3G), while in the extract with the lowest concentration of anthocyanins (1 mg in 1 mL of simulated gastric fluid - SGF) it was possible to recover only 21% of C3G and no D3G. The intestinal phase led to the total disappearance of D3G and C3G from the extract with the lowest concentration of anthocyanins, while in the extract with the highest levels of anthocyanins, the recovery of C3G dropped to 26%.

Furthermore, Dantas et al. (2019), who analyzed eight fruits (*Euterpe oleracea* Mart, *Theobroma grandiflorum*, *Rubus* spp., *Vaccinium myrtillus* L., *Myrciaria jaboticaba*, *Rubus idaeus*, *Spondias mombin* L., and *Annona muricata*), reported that exposure to conditions that simulate gastrointestinal digestion reduces anthocyanin content in frozen pulps that have a red-

purple color. The authors described the bioaccessible fraction of catechin (99.52%), procyanidin B1 (43.30%) and Kaempferol glucoside (7.01%) in jaboticaba pulp.

According to Inada et al. (2020a), the bioaccessibility of the total phenolic compounds of pulp and seed of *Plinia jaboticaba* is 49%. In addition, the researchers observed that the relative release of C3G and D3G after intestinal digestion decreased by an average of 25% compared to gastric digestion. After intestinal digestion, an increase in the relative release of ellagic acid (74%), quercetin-3-O-rutinoside (53%), quercetin (34%) and gallic acid (17%) was observed.

Quatrin et al. (2020), described the bioaccessibility of several polyphenols in *M. trunciflora* peel, explaining the relationship between them. According to the authors, the ellagitannins and gallotannins present in the peel showed greater degradation (-44%) than anthocyanins (-7.6%) in the first stage (salivary digestion). After gastric digestion, a significant reduction in hydrolysable tannins (-58.2%) was reported, mainly HHDP-galloylglucose isomer (-93.8%) and Bis-HHDP-galloylglucose (Casuarinin)+HHDP-galloylglucose (-97.5%), however, the hydrolysis of these compounds resulted in an increase in gallic acid contents (+23.2%). This effect was even more representative after the intestinal phase, in which the concentration of gallic acid increased 820%, as well as elagic acid (+60.9%), because of significant reductions in the concentrations of hydrolyzable tannins, which presented up to 100% as with Pedunculagin. The recovery of trigaloalklicosis and its isomers after the intestinal digestion ranged from 16.5% to 61%, while for tetragaloalglycosis and its isomer recovery ranged from 48% to 96.6%. Despite the lower recovery, trigaloalklicosis and its isomers had greater bioaccessibility (2.3 to 8.5%) than tetragaloalglycosis and its isomer (0.0 to 1.1%).

Quatrin et al. (2020) reported that the free ellagic acid from *M. jaboticaba* peel shows a reduction after the salivary (-19.8%) and gastric (-9.6%) digestion steps. However, after the intestinal phase, the ellagic acid content increases by 60.9%, probably because of the hydrolysis

undergone by the ellagiotannins. In addition, ellagic acid has a higher bioaccessible fraction (32.4%) than gallic acid (6.7%).

Regarding flavonols, Quatrin et al. (2020) described a significant reduction in the levels of myricetin, quercetin and their derivatives at all stages of digestion (salivary: -43.4%; gastric: -53.5%; intestinal: -59.5%) and that the bioaccessibility varied between 0.0% (myricetin-hexoside) and 36.8% (quercetin-pentoside). Anthocyanins did not suffer as much in the salivary (Delphinidin-3-glucoside: +0.65; Cyanidin-3-glucoside: -8.3; Peonidin-3-glucoside: -9.7) and gastric (D3G: -29%; C3G: -14.9; P3G: -16.1%), but showed a significant reduction after the intestinal stage (D3G: -97.6%; C3G: -88.6%; P3G: -86.7%), affecting the bioaccessible fraction (D3G: -0.1%; C3G: -1.4%; P3G: -2.3%).

### 3.4.1 *Carotenoids*

Carotenoids are fat-soluble pigments responsible for the colors red, orange and yellow. Naturally dispersed in the animal and plant kingdom, photosynthetic organisms produced them, such as plants, algae and cyanobacteria. However, animals must get them through diet (Maoka, 2019; Mezzomo & Ferreira, 2016; Ngamwonglumlert et al., 2020). Chemically, these compounds are hydrocarbons composed of 40 carbon atoms (tetraterpenes, C<sub>40</sub>) and two terminal rings, presenting a linear and symmetrical distribution. The system of conjugated double bonds gives these pigments high chemical reactivity that can be easily isomerized and oxidized. Its basic structure can undergo changes when undergoing hydrogenation, dehydrogenation, cyclization, and oxidation (Mezzomo & Ferreira, 2016).

These pigments have several functions in the human body, highlighting their antioxidant, anti-inflammatory, anti-cancer, anti-tuberculosis, anti-microbial, immunity booster and UV protectant action (Bhatt & Patel, 2020). Besides having a protective effect against

cardiovascular, ophthalmic and neurodegenerative diseases, as well as diabetes and metabolic syndrome (Arunkumar et al., 2020; Bhatt & Patel, 2020; Haaker et al., 2020).

There were few studies about these compounds. Some of them described considerable levels of total carotenoids in aqueous extract of *P. jaboticaba* peel powder ( $35.86 \pm 5.13 \text{ mg.g}^{-1}$  of peel powder) (Silva-Maia et al., 2019), and epicarp and mesocarp of *P. cauliflora* (Biazotto et al., 2019), which vary between 1.52 and  $3.27 \mu\text{g/g}$  of edible fraction, according to the origin of the fruit. These levels are considered moderate, according to the scale proposed by Britton & Khachik (2009) (low:  $0-1 \mu\text{g.g}^{-1}$ ; moderate:  $1-5 \mu\text{g.g}^{-1}$ ; high:  $5-20 \mu\text{g.g}^{-1}$ ; very high:  $>20 \mu\text{g.g}^{-1}$ ).

Jaboticaba has similar carotenoid values to other fruits of the Myrtaceae family, such as *Syzygium cumini* ( $0.9 \mu\text{g.g}^{-1}$ ), *Syzygium malaccense* (0.01 to  $3.93 \mu\text{g.g}^{-1}$ ), *Eugenia pyriformis* (2.07 to  $2.56 \mu\text{g.g}^{-1}$ ) and *Campomanesia xanthocarpa* (3.22 to  $7.22 \mu\text{g.g}^{-1}$ ) (Farias et al., 2020).

Inada et al. (2015) reported that  $\beta$ -carotene was the only carotenoid possible to identify and quantify in pulp of *M. jaboticaba* ( $8.73 \mu\text{g.g}^{-1}$ , d.w.;  $0.73 \mu\text{g}$  retinol activity equivalent.g<sup>-1</sup>, d.w.). While a more recent study (Biazotto et al., 2019) on epicarp and mesocarp of *P. cauliflora* reported the presence of (all-E)-Lutein ( $0.82$  to  $1.72 \mu\text{g.g}^{-1}$  edible fraction) and (all-E)- $\beta$ -Carotene ( $0.33$  to  $0.99 \mu\text{g.g}^{-1}$  edible fraction).

On the other hand, Farias et al. (2020) identified lutein, neoxanthin, violaxanthin, zeaxanthin, Phytoene,  $\beta$ -cryptoxanthin, Phytofluene,  $\alpha$ -carotene,  $\beta$ -carotene and zeinoxanthin, among other carotenoids in other fruits of the Myrtaceae family (*Syzygium cumini*, *Eugenia pyriformis*, and *Campomanesia xanthocarpa*), but did not identify any carotenoids in *Syzygium malaccense*.

Although only two carotenoids have been identified in jaboticaba, lutein and  $\beta$ -carotene are known for their benefits to human health, mainly in their action on vision. Lutein, zeaxanthin, meso-zeaxanthin and their oxidative metabolites are selectively accumulated in the

macula lutea region of the human retina, after crossing the blood-retinal barrier, being known as macular pigments (Arunkumar et al., 2020; Johnson, 2012). These compounds filter high-intensity, short-wavelength visible light and have antioxidant action, which is necessary to contain light-induced oxidative stress (Arunkumar et al., 2020). Furthermore, these compounds accumulate in the human brain, improving overall cognitive function, memory retention and verbal fluency (Hammond-Junior et al., 2017; Johnson, 2012).

$\beta$ -carotene undergoes cleavage by the action of the enzyme 15-15'  $\beta$ -carotene dioxygenase. The resulting product is retinal, which can be reversibly converted to retinol (vitamin A) and irreversibly to retinoic acid (Ambrósio et al., 2006). Retinoic acid (RA) is generated in the retina during eye development. Retinol is converted to retinaldehyde by retinol dehydrogenase 10 (RDH10) and then to AR by the three retinaldehyde dehydrogenases (ALDH1A1, ALDH1A2 and ALDH1A3). AR is required for further morphogenesis of the optic cup and surrounding periorbital mesenchyme (Duester, 2022). In addition, all-trans retinols are formed in the outer segments of human cone photoreceptors, which leads to faster regeneration of visual cone pigment (Milliken et al., 2018).

### ***3.4 Volatile organic compounds***

Found in plants, volatile organic compounds (VOCs) are a group of naturally occurring lipophilic compounds with low molecular weight and high vapor pressure at room temperature (Dudareva et al., 2012; Pichersky et al., 2006). These compounds can cross membranes freely and evaporate into the atmosphere when they do not meet any barrier to their diffusion (Pichersky et al., 2006).

A single plant can produce thousands of volatile compounds through primary and secondary metabolism (Goff & Klee, 2006). VOCs are produced at different stages of plant development, and stand out for their flavor. These compounds can help plants in the pollination,

by attracting dispersers (Goff & Klee, 2006; Pichersky et al., 2006). Several compounds can be precursors of VOCs, among them are fatty acids, carotenoids and some amino acids (leucine, isoleucine and phenylalanine) (Goff & Klee, 2006).

VOCs are widely found in fruits, and their levels are high in spices. Most VOCs cannot be detected because of their low concentration. The VOCs signal that the fruit is ready to be consumed. So, its contents are associated with the stage of development of the plants, since its levels increases with the course of maturation. (Goff & Klee, 2006).

Most VOCs present in fruits are aliphatic compounds characterized by saturated and unsaturated molecules that present as ester, alcohol, acid, aldehyde, ketone or lactone functional groups (Sanabria et al., 2018).

Only two studies were found that quantified VOCs in jaboticaba (Table 6), especially citric acid contents. However, other studies have identified several volatile compounds in different jaboticaba varieties (Dallabona et al., 2020; Freitas et al., 2020; Jham et al., 2007; Sanabria et al., 2018).

Jham et al. (2007) identified the acids oxalic, succinic, fumaric, glutaric, malic, tartaric, citric and quinic in *M. cauliflora* and *M. jaboticaba* pulps, and reported the concentration of citric acid (*M. cauliflora*: 14.79 to 16.51 mg.g<sup>-1</sup>; *M. jaboticaba*: 30.64 to 61.56 mg.g<sup>-1</sup>) and succinic acid (*M. cauliflora*: 30.64 to 61.56 mg.g<sup>-1</sup>; *M. jaboticaba*: 13.95 to 46.52 mg.g<sup>-1</sup>). Furthermore, Jham et al. (2007) observed that the choice of solvents directly influences the content of the extracted compounds, recommending extraction in water. However, different methods (GC or HPLC) for identification and quantification of these compounds does not influence the result.

**Table 6.**Volatile organic compounds of jaboticaba jaboticaba (mg.100 g<sup>-1</sup>, d. w.).

Volatile organic compounds	Albuquerque et al. (2020) <sup>1</sup> <i>M. jaboticaba</i> Peel	Morales et al. (2016) <sup>1</sup> <i>M. cauliflora</i> Pomace
Oxalic acid	0.481 ± 0.01	0.33 ± 0.02
Quinic acid	0.554 ± 0.00	0.60 ± 0.02
Malic acid	1.66 ± 0.01	0.11 ± 0.01
Shikimic acid	0.125 ± 0.01	0.41 ± 0.01
Citric acid	18.8 ± 0.1	14.5 ± 0.3
Total organic acids	21.67 ± 0.09	

<sup>1</sup>Values presented as mean ± standard deviation.

Citric acid has pharmaceutical applications like capping agent, coating agent, green crosslinker, stabilizer, disintegrant, fluorescent material, solvent, absorption enhancer, dendrimers, co-crystal former, polymer nanoconjugates, gas-generating agent, and pH modifier (Nangare et al., 2021). On the other hand, succinic acid is a food additive approved by the Food and Drug Administration (FDA), and its main uses include bath preparations, detergents, cosmetics, pigments, reagents for the synthesis of pharmaceuticals and production of degradable polymers (Fumagalli, 2006).

Sanabria et al. (2018) described a greater variety of volatile organic compounds in *Myrciaria jabuticaba* pulp: alcohols (ethanol, 3-methyl-1-butanol, (Z)-3-hexenol, and 1-hexanol), aldehydes (3-methyl-1-butanal, pentanal, hexanal, (E)-2-hexenal, nonanal, and decanal), aromatic compounds (styrene, benzaldehyde, 1,3-dichlorobenzene, and *p*-cymene), esters (ethyl acetate, ethyl propanoate, propyl acetate, methyl (E)-2-butenoate, 2-methylpropyl acetate, ethyl butanoate, ethyl (E)-2-butenoate, 3-methylbutyl acetate, methyl (E)-2-hexanoate, ethyl hexanoate, (Z)-3-hexenyl acetate, (Z)-3-hexenyl butanoate, ethyl octanoate, and methyl 3-phenylpropenoate), ether (ethyl ether), ketones (2-heptanone), terpenoids (tricyclene, α-pinene, sabinene, β-pinene, β-myrcene, α-phellandrene, limonene, eucalyptol, (E)-β-ocimene, γ-terpinene, terpinolene, linalool, 1,3,8-p-menthatriene, (4E,6Z)-allo-ocimene, α-terpineol, δ-elemene, α-cubebene, α-copaene, β-cubebene, β-elemene, β-caryophyllene, aromadendrene, α-

guaiene,  $\beta$ -gurjunene,  $\beta$ -farnesene,  $\alpha$ -elemene, allo-aromadendrene,  $\alpha$ -caryophyllene,  $\gamma$ -muurolene, eremophilene, germacrene d, valencene,  $\alpha$ -selinene, epizonarene,  $\alpha$ -muurolene,  $\gamma$ -cadinene,  $\delta$ -cadinene, calamenene, naphthalene, 1,2,3,4,4a,7-hexa-hydro-1,6-dimethyl-4-(1-methylethyl)-germacrene B, and caryophyllene oxide), and saturated hydrocarbons (n-hexane).

Furthermore, the work reported above (Sanabria et al., 2018) highlighted the representative contents of some compounds based on the relative percentage of the graph area: limonene (17.71%), ethyl acetate (10.71%), 1,3-dichlorobenzene (9.70%), eucalyptol (5.79%), and  $\beta$ -caryophyllene (5.01%).

The limonene is a well-identified monoterpene that is commonly applied as a fragrance ingredient in essential oils. This compound presents remarkable therapeutic effects like antioxidant, anticancer, anti-inflammatory, antidiabetic and anti-glycating, gastroprotective, antiatherogenic, hypolipidemic, cardioprotective, anti-fibrotic, immunomodulatory, anti-stress, hepatoprotective, anti-genotoxic and renoprotective (Anandakumar et al., 2020; Vieira et al., 2018). While, eucalyptol has a cardioprotective effect and improvement in respiratory mechanics, because of its recognized antioxidant and anti-inflammatory action (Fazelan et al., 2020; Gondim et al., 2018; Santos et al., 2011).

A wide variety of compounds have been described in *P. cauliflora* peel (Dallabona et al., 2020): terpenes (o-cymene, ( $-$ )-cis-sabinol, and car-3-en-5-one, D-germacrene,  $\alpha$ -muurolene,  $\gamma$ -cadinene,  $\delta$ -cadinene, elemol, spathulenol, (+)-isospathulenol,  $\tau$ -cadinol,  $\tau$ -muurolol,  $\alpha$ -muurolene-14-ol, ent-germacra-4(15),5,10(14)-trien-1 $\beta$ -ol, 6-isopropenyl- 4,8a-dimethyl-1,2,3,5,6,7,8,8a-octahydro-naphthalen-2-ol, shyobunol, longifolenaldehyde, oplopanone, eudesma-4(14),7-dien-1 $\beta$ -ol, 6-epi-shyobunol, platambin, trans-geranylgeraniol, and phytol), esters (triacetin, isobutyl phthalate, ethyl palmitate, hexanedioic acid, bis(2-ethylhexyl) ester, and 2-(dimethylamino)ethyl carbamate), and other compounds (coumaran, 1,6-anhydro- $\beta$ -D-glucopyranose, 2(3H)-benzothiazolone, and linoleic acid). Stood out, with

larger relative areas of the graph, phytol (8.57%), linoleic acid (7.34%), 6-epi-shyobunol (5.98%), and  $\tau$ -Muurolol (5.95%).

Phytol is a diterpene member of the long-chain unsaturated acyclic alcohols. Studies report anxiolytic, metabolism-modulating, cytotoxic, antioxidant, autophagy- and apoptosis-inducing, antinociceptive, anti-inflammatory, immune-modulating, and antimicrobial effects (Islam et al., 2018). However, linoleic acid is a fatty acid found naturally in food, has been identified as a potential anti-obesogenic agent, anti-obesogenic effect, and anti-atherosclerotic properties (Hartigh, 2019; Marangoni et al., 2020).

Finally, Freitas et al. (2020) identified 117 VOCs in pulp and peel of four jaboticaba varieties (*P. jaboticaba*; *P. cauliflora*; *P. phitrantha*, and Scarlate – mix of *P. phitrantha* and *P. cauliflora*), which were distributed in the following classes: alcohol, aldehyde, alkane, ester, ketone, monoterpene, monoterpenoid alcohol, sesquiterpene, sesquiterpenoid and ester.

According to Freitas et al. (2020), *P. jaboticaba* stands out for the presence of esters, which have an aroma with fruity, green and sweet notes. On the other hand, scarlet varieties (*P. phitrantha* and *P. cauliflora*) and *P. cauliflora* presented a wide variety of sesquiterpenes, known for their woody, fruity, floral and sweet aromas. The most abundant aroma of *P. cauliflora* is the green-herb-woody aroma, because of thujene, while the scarlet variety stands out for the contents of sesquiterpene  $\alpha$ -muurolene with a woody aroma. The researchers highlighted that the aromatic profile of the jaboticaba species analyzed presents differences that can be attributed to genetic variability of the species, considering that all jaboticaba were cultivated under the same environmental conditions.

The presence of terpene groups is very common in fruits of the Myrtaceae family. Of the 32 compounds identified in *Syzygium cumini*, 25 are terpenes (mainly  $\alpha$ -gurjuene and  $\alpha$ -caryophyllene), especially sesquiterpenes (Farias et al., 2020). The same can be observed for *Eugenia pyriformis*, of the 72 compounds identified, 41 are terpenes (mainly  $\beta$ -caryophyllene

and elixene). For *Campomanesia xanthocarpa*, out of 55 VOCs described, 17 are terpenes and 17 are alcohols, and for *Syzygium malaccense*, of the 28 compounds identified, only 3 are terpenes, the majority being alcohol (14 compounds) (Farias et al., 2020).

Sesquiterpenes are colorless, bitter, relatively stable lipophilic constituents (Rodriguez et al., 1976). Known to have antitumor, cytotoxic, antimicrobial and phytotoxic action (Amorim et al., 2013; Babaei et al., 2018; Rodriguez et al., 1976).

#### 4 CONCLUSION

The whole jaboticaba fruit stood out for its high levels of total polyphenols (1196.5 to 2031.1 mg GAE.100 g<sup>-1</sup>), mainly anthocyanins (cyanidin and delphinidin), ellagic acid, methylellagic acid, gallic acid, myricetin, quercetin, castalagin, pedunculagin and vescalagin. These compounds have recognized anti-inflammatory, anticancer, antidiabetic, antitoxic, cardio and neuroprotective functions.

When evaluating the behavior of these compounds after *in vitro* digestion, it is observed that anthocyanins did not suffer as much in the salivary and gastric stages, but showed a significant reduction after the intestinal stage. However, ellagitannins and gallotannins showed great degradation (-44%) right in the first stage. As well as myricetin, quercetin and their derivatives, which reduce at all stages (salivary: -43.4%; gastric: -53.5%; intestinal: -59.5%). After gastric digestion, a significant reduction in hydrolysable tannins was reported (-58.2% to -97.5%), but the hydrolysis of these compounds reflected an increase in gallic and ellagic acids contents (+820%; +60.9%).

*Plinia* sp. has moderate levels of carotenoids (1.52 and 3.27 µg.g-1). However, few studies were found regarding the profile of these compounds in jaboticaba. However, the presence of (all-E)-Lutein and (all-E)-β-Carotene, which are known as macular pigments, has

been reported, besides accumulating in the human brain, improving overall cognitive function, memory retention and verbal fluency.

Furthermore, studies were found that highlighted the levels of citric acid and succinic acid in *M. cauliflora* and *M. jabuticaba*, which have important roles in the pharmaceutical and food industry. The fruits are washed down by the presence of esters, which have an aroma with fruity, green and sweet notes, and sesquiterpenes, known for their woody, fruity, floral and sweet aromas.

In this way, the great relevance of the fruit and its potential for application in the pharmaceutical and food industries is highlighted. However, it should be noted that the subject has not been exhausted, since there is a great lack of studies about the profile and bioaccessibility of carotenoids in jaboticaba fruits. Thus, further studies are suggested.

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## **CAPÍTULO II**

### **BIOACESSIBILIDADE DE CAROTENOIDES DE BURITI, JAMBOLÃO E JABUTICABA**

**Artigo 4:** Bioacessibilidade de carotenoides em *M. flexuosa* por digestão *in vitro*

**Artigo 5:** Bioacessibilidade de carotenoides em polpa de *Syzygium cumini* e fruto inteiro de *Plinia jaboticaba* (Vell.) Berg por digestão *in vitro*

## **Artigo 4**

### **Bioacessibilidade de carotenoides em *M. flexuosa* após digestão *in vitro***

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## Bioacessibilidade de carotenoides em *M. flexuosa* por digestão *in vitro*

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### Resumo

O buriti, *Mauritia flexuosa*, tem chamado a atenção dos pesquisadores devido ao seu grande potencial bioativo, destacando-se os teores de carotenoides, sobretudo β-caroteno.

Entretanto, há poucos estudos na literatura científica que descrevem e quantificam o perfil de carotenoides nesta matriz alimentar. Além de não ser possível encontrar nenhum estudo que descreva seu comportamento perante o processo digestivo. Assim, objetivou-se descrever o perfil de carotenoides em polpa de *M. flexuosa* e sua fração bioacessível.

Dessa forma, este estudo é o pioneiro na realização de digestão *in vitro* em polpa de *M. flexuosa*, o que possibilitou a descrição e quantificação dos compostos em quimo e fração micelar. No fruto foram identificados fitoeno, fitoflueno, e β-caroteno, totalizando 143,49 µg.g<sup>-1</sup> e 2.048,4 µg RAE. No quimo, foi possível a identificação e luteína, fitoeno, α-

criptoxantina e  $\beta$ -criptoxantina, somando  $7,26 \mu\text{g} \cdot \text{g}^{-1}$  e  $158,4 \mu\text{g}$  RAE. Por fim, na fração micelar foi possível identificar apenas  $\beta$ -criptoxantina ( $0,11 \mu\text{g} \cdot \text{g}^{-1}$ ;  $2,64 \mu\text{g}$  RAE). Deste modo, estes achados indicam que a polpa de *M. flexuosa* apresenta importantes carotenoides, sobretudo provitamina A e macular, substâncias de grande relevância na saúde humana.

**Palavras-chave:** APCI, Alimentos Funcionais, Composição Proximal, Espectrometria de Massa, Nutrientes.

## Abstract

The buriti, *Mauritia flexuosa*, has drawn the attention of researchers due to its great bioactive potential, highlighting the carotenoid contents, especially  $\beta$ -carotene. However, there are few studies in the scientific literature that describe and quantify the carotenoid profile in this food matrix. Besides, it is not possible to find any study that describes its behavior in the digestive process. Thus, this work aimed to describe the carotenoid profile in *M. flexuosa* pulp and its bioaccessible fraction. This study is the pioneer in carrying out *in vitro* digestion in *M. flexuosa* pulp, which allowed the description and quantification of the compounds in chyme and micellar fraction. Phytoene, phytofluene, and  $\beta$ -carotene were identified in the fruit, totaling  $143.49 \mu\text{g} \cdot \text{g}^{-1}$  and  $1,665.36 \mu\text{g}$  RAE. In the chyme, it was possible to identify lutein, phytoene,  $\alpha$ -cryptoanthin and  $\beta$ -cryptoanthin, adding up to  $7.26 \mu\text{g} \cdot \text{g}^{-1}$  and  $158.4 \mu\text{g}$  ERA. In the micellar fraction it was possible to identify only  $\beta$ -cryptoanthin ( $0.11 \mu\text{g} \cdot \text{g}^{-1}$ ;  $2.64 \mu\text{g}$  RAE). Thus, these findings indicate that the pulp of *M. flexuosa* presents important carotenoids, which are of great importance in human health, highlighting the presence of provitamin A carotenoids and the main macular carotenoid.

**Keywords:** APCI, Functional food, Proximate Composition, Mass spectrometry, Nutrients.

## 1. Introdução

O buriti, *Mauritia flexuosa* L. f., é uma palmeira da família Arecaceae. Habita regiões alagadas e nascentes, muitas vezes em baixas altitudes, margeando rios, córregos e lagos. Esta palmeira está distribuída por toda a América do Sul e pode ser encontrada no Brasil, Bolívia, Colômbia, Equador, Guianas, Peru, Venezuela e Trinidad e Tobago. É considerada a palmeira mais abundante no Brasil (EMBRAPA, 2006).

O fruto pode ser consumido como suco, bala, sorvete e óleo, ou utilizada na produção de artesanato, material de construção, cosméticos e produtos farmacêuticos. Muitas comunidades ribeirinhas e indígenas utilizam essa palmeira para seu sustento e algumas se dedicam à comercialização do fruto ou artesanato feito de outras partes da palmeira, como as folhas e fibras do caule (Virapongse et al., 2017).

Estudos indicam que o fruto se destaca por suas altas concentrações de lipídios, principalmente ácido oleico e palmítico, e teores consideráveis de açúcar e fibras, principalmente pectina (Berni et al., 2019; Lescano et al., 2018; Mesquita et al., 2020; Nascimento-Silva et al., 2020; Parente et al., 2020; Schiassi et al., 2018). Entretanto, o que tem chamado a atenção dos pesquisadores é seu grande potencial bioativo.

Está bem estabelecido na literatura que a polpa de buriti se destaca por seus teores de carotenoides (349,9 a 632,2  $\mu\text{g.g}^{-1}$ ) (Cândido et al., 2015; Godoy & Rodriguez-Amaya, 1994; Nascimento-Silva et al., 2020; Rosso & Mercador, 2007). No entanto, poucos estudos descreveram e quantificaram seu perfil de carotenoides (Cândido et al., 2015; Godoy & Rodriguez-Amaya, 1994; Rosso & Mercadante, 2007). Esses estudos

chamaram a atenção ao identificar níveis significativos de carotenoides provitamina A, como  $\alpha$ -caroteno e  $\beta$ -caroteno na polpa de *M. flexuosa* e *M. vinifera*.

Estes compostos têm grande importância na saúde humana e são reconhecidos na comunidade científica, uma vez que são encontrados em elevadas concentrações no sangue humano. São utilizados na produção de retinol e ácido retinóico, além de apresentarem função antioxidante e serem associados como fator de proteção contra câncer, degeneração macular, catarata, entre outras doenças (Rodriguez-Amaya & Kimura, 2004).

Um fator importante a ser considerado quando se trata de compostos bioativos é a fração bioacessível, uma vez que vários fatores podem afetar no teor e perfil de compostos que ficam disponíveis para serem assimilados e metabolizados (Thakur et al., 2020). Fatores dietéticos (concentração de lipídeos e fibras), conteúdo e tipo de carotenoides, localização do carotenoide no tecido vegetal, interações entre carotenoides, tamanho de partícula de alimento, tratamento térmico, e características do sujeito podem influenciar na biodisponibilidade de carotenoides. Portanto, mesmo quando estes compostos estão em quantidades relevantes, sua utilização pode ser insatisfatória (Priyadarshani, 2017).

A determinação da fração bioacessível fornece informações valiosas a respeito da dosagem recomendada de cada composto e a fonte alimentar correspondente, de maneira a garantir sua adequada eficácia nutricional (Fernández-García; Carvajal-Lérida; Pérez-Gálvez, 2009).

Sendo assim, objetivou-se descrever o perfil de carotenoides em polpa de *M. flexuosa* e sua fração bioacessível, de modo a esclarecer as lacunas encontradas na literatura científica. Esses dados podem servir de subsídio para aumentar o valor agregado ao buriti, valorizá-lo como alimento funcional, expandir o seu consumo e ter

consequências diretas na segurança econômica e alimentar das populações locais envolvidas na sua coleta e distribuição.

## **2. Material e métodos**

### *2.1. Amostras*

Frutos maduros de buriti, da variedade *M. flexuosa* foram coletados em dezembro de 2019 em Caldazinha, Goiás, Brasil (latitude: -16.7047, longitude: -48.9954). Os frutos foram coletados durante o período de safra, sendo selecionados de acordo com o ponto ótimo de maturação e suas condições morfológicas. Assim, foram selecionados os frutos que caíram naturalmente da planta e que estavam íntegros, livres de deformidades ou micro-organismos. Os frutos foram sanitizados com hipoclorito de sódio (2 ppm) e armazenados à temperatura ambiente até que as escamas desprendessem naturalmente da polpa. Então, a polpa foi manualmente separada das demais partes do fruto com faca inox, embalada sob vácuo em sacos de polietileno de baixa densidade protegidos da luz, e armazenada até o momento das análises sob congelamento a -20 °C.

### *2.2. Composição proximal*

Os teores de umidade (método nº 934.06) e cinzas (método nº 940.26) da polpa de buriti foram obtidos por gravimetria após secagem da amostra a 105 °C e carbonização a 550 °C até peso constante, respectivamente (AOAC, 2019).

Para determinar os valores de proteína bruta, foi utilizado o método micro-Kjeldahl (AOAC, 2019 - método nº 920.152), que determina a matéria total de nitrogênio na amostra. Digeriu-se 0,2 g de amostra em 5,0 mL de ácido sulfúrico PA e mistura de catalisador a 350 °C, e então o nitrogênio da amostra é destilado e coletado em um

erlenmeyer contendo 10,0 mL de ácido bórico e 3 gotas de indicador de Andersen. Em seguida, o destilado é titulado com uma solução de ácido clorídrico (0,02 mol/L), sendo convertido em proteína, utilizando o fator de conversão 6,25.

O conteúdo lipídico total foi determinado seguindo a metodologia descrita por Bligh & Dyer (1959). De acordo com o qual, 3,0 g de amostra foram homogeneizados com 10,0 ml de clorofórmio, 20,0 ml de metanol e 8,0 ml de água em agitador rotativo por 30 min. Em seguida, 10,0 mL de clorofórmio e 10,0 mL de sulfato de sódio (1,5%) foram adicionados à amostra, que foi agitada vigorosamente por 2 min. A solução foi armazenada à temperatura ambiente durante 12 horas. Após a separação, a fase aquosa foi descartada e a camada inferior foi filtrada em papel filme e coletada em placa de Petri. O solvente foi evaporado em uma capela e o teor de lipídios foi determinado por diferença de peso.

O teor de carboidratos totais foi estimado por diferença, subtraindo-se os valores de umidade, proteína bruta, cinzas e lipídios de 100. O valor energético total das amostras foi calculado com os seguintes fatores de conversão: 4,0 kcal/g de proteína e carboidratos totais e 9,0 kcal/g de lipídios (Merril & Watt, 1973).

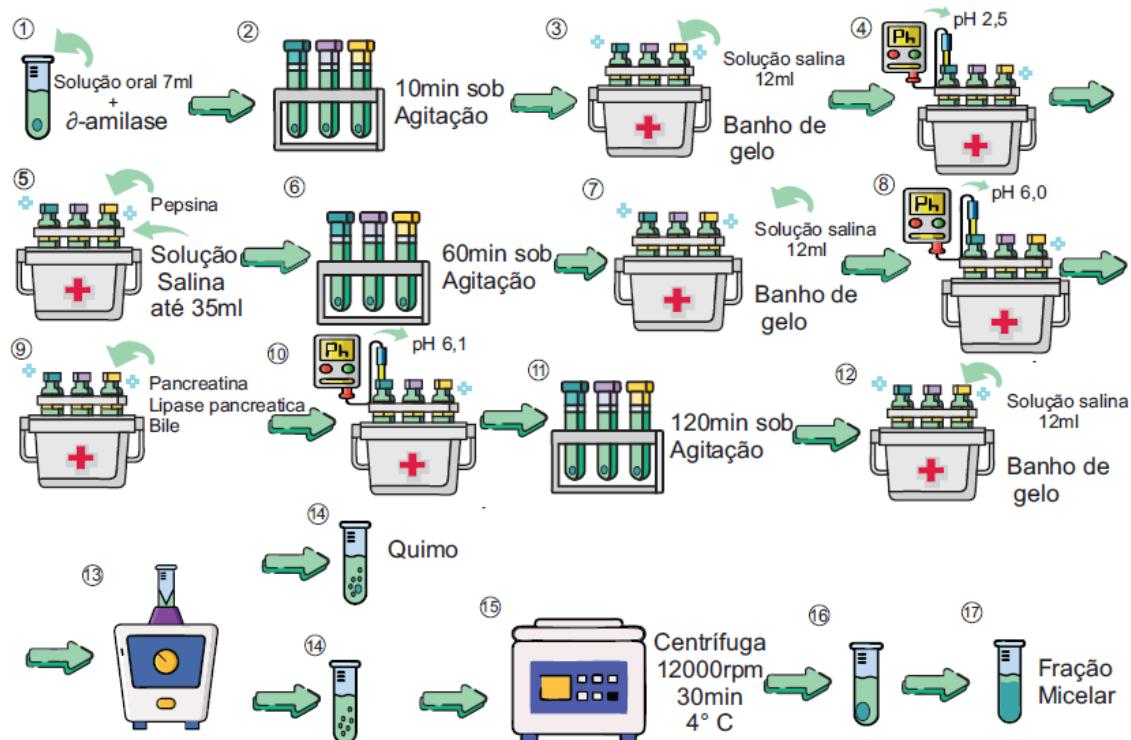
### 2.3. Bioacessibilidade *in vitro*

A digestão *in vitro* foi realizada de acordo com o proposto por Rodrigues et al. (2017), com modificações (Fig. 1). A digestão foi dividida em três fases: oral, gástrica e intestinal. Inicialmente se pesou 1,0 g de amostra em tubo de vidro, ao qual foi adicionada solução salivar salina (NaCl, KCl, CaCl<sub>2</sub>, ureia, ácido úrico, mucina e α-amilase). Esta solução foi submetida a aquecimento (37 °C) por 10 minutos sob agitação (85 rpm). Ao final do tempo, o pH da solução foi corrigido para 2,5 e iniciou-se a fase gástrica, na qual, solução contendo pepsina e solução salina (NaCl, KCl, CaCl<sub>2</sub>) foram adicionadas ao tubo.

Este foi mantido em aquecimento ( $37^{\circ}\text{C}$ ) por 60 minutos sob agitação (85 rpm). Em seguida, iniciou-se a fase intestinal corrigindo o pH para 6,0 e se acrescentou solução pancreática (pancreatina e lipase pancreática) e solução biliar. A solução foi mantida sob aquecimento ( $37^{\circ}\text{C}$ ) por 120 minutos sob agitação (85 rpm). Por fim, a solução final (quimo) foi separada para extração de carotenoides ou passou por centrifugação, sendo separada a fração micelar, que também foi utilizada para extração de carotenoides.

A percentagem de fração bioacessível foi calculada de acordo com a equação a seguir:

$$\% \text{ Bioacessibilidade} = \left( \frac{\text{Concentração de carotenoides na micela}}{\text{Concentração de carotenoides na polpa do fruto}} \right) \times 100$$

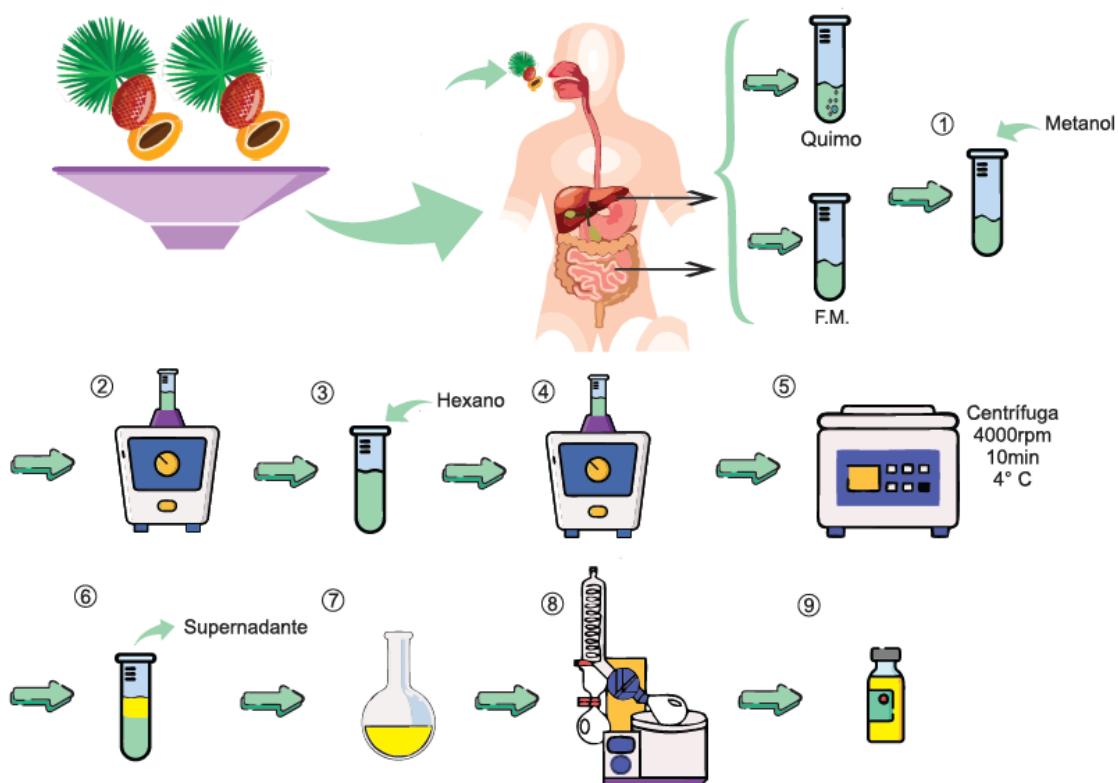


**Fig. 1.** Análise de bioacessibilidade *in vitro* segundo Rodrigues et al. (2017), com modificações.

## 2.4. Extração de carotenoides

Os carotenoides da polpa de *M. flexuosa*, assim como do quimo e da fração micelar foram extraídos de acordo com o sugerido por Rodrigues et al. (2017), com modificações (Fig. 2). Resumidamente, adicionou-se 10 mL de metanol à amostra e se submeteu o tubo de vidro a agitação em vórtex por 1 minuto. Em seguida, acrescentou-se 5 mL de hexano, e mais uma vez o tubo foi submetido a vórtex po 1 minuto. Por fim, o tubo foi centrifugado (4000 rpm a 4 °C por 10 minutos) e o sobrenadante foi coletado e transferido para balão de fundo redondo. O processo se repetiu exaustivamente até que não fosse possível observar qualquer coloração no solvente. Ao final do processo, o extrato foi seco em evaporador rotativo e armazenado a -80 °C até o momento das análises.

É importante salientar que as amostras não foram saponificadas, de modo a permitir a identificação de ésteres de carotenoides, caso houvessem.



**Fig. 2.** Extração de carotenoides segundo Rodrigues et al. (2017), com modificações.

## 2.5 Separação e identificação de carotenoides em HPLC-DAD-MS/MS

Para a análise dos carotenoides foram aplicadas as condições cromatográficas e de espectrometria de massas utilizadas por Murador et al. (2019). A separação dos compostos foi conduzida em coluna C30 YMC (5 µm, 250 x 4,6 mm d.i.) (Waters, Wilmington, NC, EUA). O equipamento utilizado para a separação e identificação dos carotenoides foi o HPLC (*High Performance Liquid Cromatography* - Cromatógrafo Líquido de Alta Eficiência) (Shimadzu, Quioto, Japão). O equipamento possui autoinjetor (SIL-20A), bomba binária (LC-20AD), desgaseificador (DGU-20A3R), e está acoplado em série aos detectores de arranjo de diodos (DAD) (Shimadzu, SPD-M20A) e de massas (LCMS 2020), que possui analisador de massa *single-quadrupole* e fonte de ionização APCI (*atmospheric pressure chemical ionization* - ionização química de pressão atmosférica).

Para realização da corrida cromatográfica se aplicou um gradiente linear com metanol (MeOH), éter metil terc-butílico (MTBE) e água (H<sub>2</sub>O) ultrapura, compondo, desta forma, as fases móveis A (MeOH/MTBE/H<sub>2</sub>O, 81:15:4) e B (MeOH/MTBE/H<sub>2</sub>O, 16:80:4). O gradiente foi desenvolvido da seguinte forma: 100% fase A durante 20 minutos, alterando para 0% fase A em 120 minutos, retornando para 100% fase A em 1 minuto, mantendo-se nesta condição por mais 10 minutos. A vazão foi de 0,8 mL/min, volume de injeção variável, com temperatura da coluna mantida a 35°C. Espectros UV-visíveis foram adquiridos entre 220 e 700 nm e os cromatogramas foram processados a 450 nm, 347 nm (para fitoflueno) e 286 nm (para fitoeno).

Os espectros de Massas foram obtidos utilizando interface APCI nos modos positivo e negativo; detector de voltagem de 1.05 kV; temperatura da interface em 350 °C; temperatura DL e do bloco de calor de 300 °C; fluxo do gás de nebulização (N<sub>2</sub>) de

2,0 L/min; fluxo do gás de secagem ( $N_2$ ) de 5,0 L/min. Estes espectros foram obtidos na faixa de razão carga/massa ( $m/z$ ) de 300 a 1200.

Para realizar a identificação dos carotenoides e dos ésteres de carotenoides presentes na polpa de *M. flexuosa* e frações após digestão *in vitro* foram utilizados os dados da eluição cromatográfica em coluna C<sub>30</sub> e as características dos espectros UV-visível ( $\lambda_{max}$ , estrutura fina espectral e intensidade do pico cis), e de massas (molécula protonada ([M+H]<sup>+</sup>) e fragmentos *in source*, além de realização de co-cromatografia utilizando padrões e ainda a comparação com dados consistentes da literatura (Azevedo-Meleiro & Rodriguez-Amaya, 2004; Breemen, Dong & Pajkovic, 2012; Britton, 2004; Rivera, Christou, & Canela-Garayoa, 2013; Rosso & Mercadante, 2007). Para confirmação da identidade dos carotenoides e quantificação dos mesmos, foram utilizadas curvas de calibração com padrões de (todo-E)-luteína, (todo-E)-zeaxantina, (todo-E)- $\alpha$ -caroteno, (todo-E)- $\beta$ -caroteno, (todo-E)- $\beta$ -criptoxantina, (todo-E)-licopeno. O teor total de carotenoides foi calculado como a soma dos conteúdos de cada carotenóide individual separados na coluna C<sub>30</sub>.

Para o cálculo do teor de Equivalente de Atividade de Retinol (*Retinol Activity Equivalent* - RAE), multiplicou-se o conteúdo de carotenoides por 12 µg (todo-trans- $\beta$ -caroteno) e 24 µg (outros carotenoides provitamina A –  $\alpha$ -caroteno e  $\beta$ -criptoxantina) (IOM, 2001).

### **3. Resultados e discussão**

#### **3.1. Composição proximal**

A polpa de *M. flexuosa* analisada neste estudo apresentou alta umidade (71,35 ± 0,10 g.100 g<sup>-1</sup>), o que torna o alimento mais suscetível à proliferação de microrganismos

patogênicos (Syamaladevi et al., 2016). Resultado semelhante foi relatado por Nascimento-Silva, Silva & Silva (2020) ( $70,00 \pm 0,35$  g.100 g<sup>-1</sup>) e Cândido & Silva (2017) ( $74,47 \pm 0,11$  g.100 g<sup>-1</sup>) para a polpa de buriti nativa de Goiás, e Schiassi et al. (2018) e Lescano et al. (2018) para frutos de São Paulo ( $79,35 \pm 0,99$  g.100 g<sup>-1</sup>) e Mato Grosso ( $73,45 \pm 0,43$  g.100 g<sup>-1</sup>), respectivamente. Ao avaliar cinco frutos nativas do Cerrado, Schiassi et al. (2018) observaram que os teores de umidade dos frutos variaram de 73,3 a 89,7 g.100 g<sup>-1</sup>.

O teor de cinzas total ( $1,62 \pm 0,57$  g.100 g<sup>-1</sup>) foi semelhante ao relatado por Aguiar & Souza (2017) para frutos nativos da Amazônia ( $1,61 \pm 0,00$  g.100 g<sup>-1</sup>), e próximo ao descrito por Nascimento-Silva, Silva & Silva (2020) ( $1,18 \pm 0,01$  g.100 g<sup>-1</sup>) e Cândido & Silva (2017) ( $1,12 \pm 0,04$  g.100 g<sup>-1</sup>) para frutos coletados em Goiás. Esse teor mineral pode ser considerado moderado, no caso dos frutos, pois ao discutir dados de 16 polpas de frutos do Cerrado, Silva & Fonseca (2016) relataram que 12 delas apresentavam teores de cinzas abaixo de 1,0 g.100 g<sup>-1</sup>, três tinham concentrações entre 1,0 e 2,0 g.100 g<sup>-1</sup> e apenas um fruto apresentou valor superior a 3,0 g/100 g (chicha).

O teor de proteína total da polpa de *M. flexuosa* discutido neste trabalho ( $1,61 \pm 0,03$  g.100 g<sup>-1</sup>) apresenta níveis semelhantes aos relatados por Nascimento-Silva, Silva & Silva (2020) ( $1,85 \pm 0,01$  g.100 g<sup>-1</sup>) e Cândido & Silva (2017) ( $1,87 \pm 0,01$  g.100 g<sup>-1</sup>) para frutos provenientes de Goiás. Este teor de proteína está dentro da faixa esperada para frutos do Cerrado brasileiro. Uma vez que, segundo Silva & Fonseca (2016), 11 entre os 16 frutos nativos deste bioma apresentam teores proteicos abaixo de 2,0 g.100 g<sup>-1</sup>.

A polpa de *M. flexuosa* se destaca por seu teor lipídico considerável ( $6,68 \pm 0,00$  g.100 g<sup>-1</sup>), pois apresenta valores superiores aos relatados para 12 frutos nativos do Cerrado discutidos por Silva & Fonseca (2016) (0,1 a 3,73 g.100 g<sup>-1</sup>). Ao comparar esse resultado com outros estudos que analisaram a polpa de buriti, podemos observar que,

mais uma vez, esses dados foram semelhantes ao relatado por Nascimento-Silva, Silva & Silva (2020) ( $9,03 \pm 0,19$  g.100 g<sup>-1</sup>) e Cândido & Silva (2017) ( $6,15 \pm 0,26$  g.100 g<sup>-1</sup>) para frutos de Goiás.

Em relação ao teor de carboidratos (18,75 g.100 g<sup>-1</sup>), a polpa do *M. flexuosa* apresenta teores significativos quando comparados a outras frutas do Cerrado, que podem variar entre 4,5 e 18,7 g.100 g<sup>-1</sup> (Schiassi et al., 2018). Essa concentração de carboidratos foi semelhante à descrita por Aguiar & Souza (2017) (18,87 g.100 g<sup>-1</sup>) para a polpa de *M. flexuosa* coletada no Amazonas, e inferior à descrita por Darnet et al. (2011) (26,2 g.100 g<sup>-1</sup>) para frutas do Pará.

O valor energético total da polpa de *M. flexuosa* analisada neste estudo é de 141,50 kcal/100 g<sup>-1</sup>. Esse resultado é semelhante ao relatado por Nascimento-Silva, Silva & Silva (2020) (131,07 kcal/100 g<sup>-1</sup>) para frutas nativas de Goiás, e inferior ao observado por Manhães & Sabaa-Srur (2011) (166,36 kcal/100 g<sup>-1</sup>) para frutas do Pará.

### 3.2. Perfil de carotenoides de *M. flexuosa* antes e após digestão in vitro

Os compostos identificados em todas as frações analisadas (fruto, quimo e fração micelar) estão detalhados na Tabela 1, e sua identificação descrita a seguir.

Todo-*trans*-fitoeno e todo-*trans*-fitoflueno foram identificados por comparação com a literatura científica, levando-se em consideração  $t_R$ ,  $\lambda_{max}$  e estrutura fina do composto, levando-se em consideração que seus resultados foram processados a 347 nm (para fitoflueno) e 286 nm (para fitoeno). O todo-*trans*-fitoflueno foi classificado como *trans* devido aos valores elevados de III/II (75,0 – 85,7 %) e tempo de retenção (30,4 – 32,8 min), uma vez que o isômero *cis* apresentam menores valores desses parâmetros.

Os compostos *cis*-β-caroteno e todo-*trans*-β-caroteno foram identificados de acordo com  $t_R$ , espectro UV-visível ( $\lambda_{max}$  e estrutura fina), massa molar (537 g.mol<sup>-1</sup>) e a

fragmentação dos compostos no MS/MS, que demonstraram reação retro-Diels-Alder através da perda do anel  $\beta$ -iona [ $M + H - 56$ ]. O  $\alpha$ -caroteno e o  $\beta$ -caroteno diferem unicamente pela posição de uma ligação dupla de um de seus anéis terminais, entretanto os fragmentos mais comuns encontrados no  $\alpha$ -caroteno são  $137\text{ }m/z$ ,  $413\text{ }m/z$  e  $457\text{ }m/z$  (Breemen, Dong & Pajkovic, 2012). O carotenoide 9-*cis*- $\beta$ -caroteno foi identificado devido ao UV-visível ( $\lambda_{max}$  e estrutura fina),  $t_R$ , massa molar ( $537\text{ g.mol}^{-1}$ ) e por apresentar o fragmento  $467\text{ }[M + H - 69]$ , que indica clivagem entre C<sub>3</sub> e C<sub>4</sub>.

Devemos salientar, que possivelmente, o  $\beta$ -caroteno encontrado é o [ $^{13}\text{C}_6$ ]- $\beta$ -caroteno, uma vez que em APCI modo positivo é comum achar o fragmento  $448\text{ }m/z$ , que indica a presença de [ $^{13}\text{C}_6$ ]- $\beta$ -caroteno, evidenciando que o tolueno parte do centro da cadeia polieno. Outro fragmento que confirma este achado é o  $419\text{ }m/z$ , que é formado pela perda de uma fração  $\beta$ -ionona da molécula protonada (Breemen, Dong & Pajkovic, 2012). Os carotenoides *cis*- $\gamma$ -caroteno e todo-*trans*- $\gamma$ -caroteno foram tentativamente identificados devido ao comparar o  $t_R$  e o espectro UV-visível encontrado com a literatura e encontrar massa molecular  $537\text{ g.mol}^{-1}$ .

A identificação do todo-*trans*-luteína se deu por seu UV-visível e espectro de massa, uma vez que apresentou massa molar com molécula protonada a  $569\text{ }m/z$  e fragmentos a  $551\text{ }[M + H - \text{H}_2\text{O}]$  e  $533\text{ }[M + H - \text{H}_2\text{O} - \text{CH}_3]$ , seguidas por fragmentos  $463\text{ }[M + H - 106]$  e  $459\text{ }[M + H - 18 - 92]$ , que indicam perdas de xileno e tolueno, respectivamente. Além disso, é importante salientar que o fragmento  $551\text{ }m/z$  corresponde à perda do grupo hidroxila do anel- $\epsilon$ , que possui maior intensidade que a molécula protonada (569 u), uma vez que a luteína difere da zeaxantina apenas pela posição de uma ligação dupla entre carbonos em um de seus anéis e é estruturalmente semelhante ao  $\alpha$ -caroteno, exceto pelo fato de os anéis serem hidroxilados (Breemen, Dong & Pajkovic, 2012; Rosso & Mercadante, 2007). Outro evento que nos leva a diferenciar os

carotenoides luteína e zeaxantina na fragmentação é que em espectrometria de massa em tandem de íons positivos APCI a fragmentação de zeaxantina costuma apresentar íons abundantes abaixo de 300  $m/z$ . A presença dos íons 495 e 430 aparecem na fragmentação de luteína, e não de zeaxantina, pois indicam a eliminação do anel  $\alpha$ -iona (Breemen, Dong & Pajkovic, 2012).

Os carotenoides *cis*- $\alpha$ -criptoxantina e todo-*trans*- $\alpha$ -criptoxantina poderiam ser facilmente confundidos com a zeinoxantina, uma vez que apresentam  $t_R$ ,  $\lambda_{max}$  e massa molecular similares, entretanto, quando o espectro de massa apresenta maior intensidade do pico 535 u em comparação ao 553, trata-se de  $\alpha$ -criptoxantina (Rosso & Mercadante, 2007). Deste modo, o composto foi identificado por seu UV-visível e análise da fragmentação dos íons.

O carotenoide todo-*trans*- $\beta$ -criptoxantina apresenta  $t_R$  e espectro UV-visível típicos. Foi possível constatar a massa molar do composto ( $553 \text{ g.mol}^{-1}$ ) e sua fragmentação, que demonstrou perda de moléculas de água ( $535 [\text{M} + \text{H} - 18]$ ), tolueno ( $461 [\text{M} + \text{H} - 92]$ ), e reação retro-Diels-Alder ( $409 [\text{M} + \text{H} - 56]$ ). Ademais, a presença do fragmento  $473 m/z$  é associada à eliminação de metil-ciclopantadieno, comumente encontrado na  $\beta$ -criptoxantina. Este composto é um carotenoide provitamina A e possui estrutura similar ao  $\beta$ -caroteno, exceto pelo grupo hidroxila em um de seus dois anéis, deste modo, a fragmentação destes compostos é análoga (Breemen, Dong & Pajkovic, 2012). O carotenoide 5,8-epoxy- $\beta$ -criptoxantina foi identificado por comparação à literatura científica, uma vez que apresenta  $t_R$  e espectro UV-visível característicos ao composto, assim como massa molar do composto ( $553 \text{ g.mol}^{-1}$ ) e fragmentação típicos, uma vez que os epóxidos de  $\beta$ -criptoxantina apresentam menores valores de  $\lambda_{max}$ , entretanto, essa diferença entre os compostos não pode ser constatada na sua fragmentação (Rosso & Mercadante, 2007).

**Tabela 1.**

Tempo de retenção ( $t_R$ ) em coluna C<sub>30</sub>, UV-visível (% III/II; % A<sub>B</sub>/II;  $\lambda_{max}$ ) e espectroscopia de massa encontrados em polpa de *M. flexuosa* (fruto, quimo e fração micelar) em HPLC-DAD-MS/MS.

Carotenoide	$t_R$ (min)	% III/II	% A <sub>B</sub> /II	$\lambda_{max}$ (nm) <sup>1</sup>	[M + H] <sup>+</sup> (m/z)	Fragmentação dos íons (m/z)	Teor de carotenoides ( $\mu\text{g}\cdot\text{g}^{-1}$ amostra fresca)
<b>Fruto</b>							
Cis-fiteno <sup>2</sup>	28,7 – 31,0	0	-	-, 277, 284	543		2,75 ± 0,13
Todo-trans-fitoflueno <sup>2</sup>	30,4 – 32,8	75,0 – 85,7	-	333, 348, 367	545		1,96 ± 0,07
13-cis-β-caroteno	34,9 – 37,1	20	20,8	340, -, 445, 467	537	481 [M + H – 56]; 465; 409 [M + H – 56]	24,74 ± 0,43
Todo-trans-α-caroteno	36,2 – 38,4	30 – 40	-	425, 446, 475	537	481 [M + H – 56]; 465; 419; 409 [M + H – 56]	20,90 ± 0,17
Todo-trans-β-caroteno	38,6 – 40,7	20 – 25	-	-, 452, 479	537	481 [M + H – 56]; 465; 419; 409 [M + H – 56]	93,14 ± 3,18
9-cis-β-caroteno	39,93 – 42,01	0,5	0,1	366, 424, 445, -	537	467 [M + H – 69]	11,02 ± 0,18
Cis-γ-caroteno	45,61 – 46,08	20	6,25	337, 424, 466, 488	537	nd	9,19 ± 0,22
Todo-trans-γ-caroteno	45,81 – 46,26			431, 459, 488	537	nd	9,57 ± 0,41
<b>TOTAL RAE</b>							<b>173,27</b> <b>2.048,4 µg RAE</b>
<b>Quimo</b>							
Todo-trans-luteína	7,0 – 7,1	60,0 – 66,7		-, 445, 473	569	551 [M + H – 18]; 533 [M + H – 18 – 18]; 495; 463 [M + H – 106]; 459 [M + H – 18 – 92]; 437; 430	0,42 ± 0,09
Todo-trans-fiteno <sup>2</sup>	14,4	0,0 – 100,0		-, 275, 284	543		0,13 ± 0,01
Cis-fitoflueno <sup>2</sup>	17,7 – 17,8	80,0 – 83,3	50,0 – 83,3	271, 333, 349, 367	545		0,11 ± 0,02
Cis-α-criptoantina	19,9	0,0	29,2 – 40,0	339, -, 445, 467	553	535 [M + H – 18]; 527; 509 [M + H – 18]; 497; 481; 465; 409 [M + H – 56]	0,33 ± 0,01
Todo-trans-α-criptoantina	21,3	20,0 – 60,0		427; 445; 474	553	535 [M + H – 18]; 461 [M + H – 92]; 409 [M + H – 56]	1,02 ± 0,05
Todo-trans-β-criptoantina	24,0	20,0 – 25,0		-, 452, 478	553	535 [M + H – 18]; 473; 461 [M + H – 92]; 409 [M + H – 56]	5,25 ± 0,51
<b>TOTAL RAE</b>							<b>7,26</b> <b>158,4 µg RAE</b>
<b>Fração micelar</b>							
5,8-epoxy-β-criptoantina <sup>2</sup>	24,6	20,0		419, 424, 439	569	535 [M + H – 18]; 461 [M + H – 92]; 409 [M + H – 56]	0,11
<b>TOTAL RAE</b>							<b>0,11</b> <b>2,64 µg RAE</b>
<b>Bioacessibilidade</b>							<b>0,077%</b>

Valores apresentados em média ± desvio padrão. <sup>1</sup>Comprimento de onda máximo em gradiente linear de metanol/MTBE. <sup>2</sup>Tentativa de identificação. RAE: Retinol Activity Equivalent (Equivalente de Atividade de Retinol); nd: não detectado.

Os carotenoides são pigmentos naturalmente encontrados em plantas e possuem reconhecida função na saúde humana, sobretudo os provitamina A ( $\alpha$ -caroteno,  $\beta$ -caroteno  $\beta$ -criptoxantina, e  $\gamma$ -carotene) e os carotenoides maculares (luteína e zeaxantina) (Arunkumar et al., 2020; Black et al., 2020; Haaker et al., 2020).

O retinol e seus derivados (retinaldeído e ácido retinoico) são produzidos a partir de carotenoides que possuem um anel  $\beta$ -ionona não substituído (Haaker et al., 2020). Estes compostos apresentam diversas funções no organismo humano, destacando-se seu papel no sistema imunológico, ao agir como barreira epitelial na mucosa do trato respiratório e intestinal, e auxiliar no processo de diferenciação de células inatas do sistema imune, como os macrófagos, neutrófilos, células dendríticas e *natural killers*; no sistema reprodutor, ao acessorar o organismo da mulher na formação dos óvulos e corpo lúteo, ao participar do processo de fixação do embrião no útero após fecundação, e ao ajudar na maturação de espermatozoides em homens; além de ser fator de proteção contra a obesidade, diabetes, síndrome metabólica, esteatose hepática e câncer (Haaker et al., 2020; Huang et al., 2018; Tepasse et al., 2021).

Comprovando o papel da vitamina A no sistema imunológico, estudo recente (Tepasse et al., 2021) associou os níveis plasmáticos desta vitamina com o agravamento de casos de paciente internados em decorrência da contaminação com Corona vírus. De acordo com o estudo, níveis plasmáticos de vitamina A em pacientes com COVID-19 diminuem significativamente durante a inflamação aguda e os níveis plasmáticos severamente reduzidos de vitamina A estão significativamente associados à Síndrome do Desconforto Respiratório Agudo e à mortalidade.

O cérebro é mais eficiente do que outros tecidos-alvo na conversão de vitamina A em seus derivados. O ácido retinóico é essencial para regular a plasticidade sináptica no hipocampo, auxiliando no processo de aprendizagem e memória. Deste modo, a deficiência de vitamina A resulta em uma deterioração dessas funções, e a falha na sinalização do ácido

retinóico pode estar associada ao declínio cognitivo normal causado pelo processo de senilidade, ou até mesmo na doença de Alzheimer e em outros distúrbios psiquiátricos (Wołoszynowska-Fraser et al., 2020).

A luteína apresenta grupos funcionais hidroxila (O–H) ligados nas posições 3 e 3' dos anéis terminais de ionona conectados por um esqueleto isoprenóide rígido de 22 carbonos com nove ligações duplas conjugadas (Arunkumar et al., 2020). A presença da hidroxila e seu número total de ligações duplas conjugadas determinam suas características químicas, como polaridade, solubilidade, absorção de luz e propriedades antioxidantes (Arunkumar et al., 2020; Carpentier et al., 2009).

O pico de absorção do pigmento macular em 460 nm corresponde ao comprimento de onda do “perigo da luz azul”, entre 450-500 nm, e é justamente nesse comprimento de onda que a luteína atua (445 nm), protegendo a retina do dano causado pelos raios UV, ao agir como filtro de luz azul que absorve entre 40 e 90% da luz azul visível de comprimento de onda curto e alta energia incidente (Arunkumar et al., 2020). Além disso, a luteína e seus isômeros podem se orientar tanto paralela quanto perpendicularmente ao plano da membrana, de modo a aumentar a rigidez da bicamada lipídica e, portanto, atuar como “rebites moleculares”, o que pode diminuir a suscetibilidade da membrana à oxidação lipídica e prevenir a degeneração macular (Arunkumar et al., 2020; Carpentier et al., 2009; Wang et al., 2007).

Outro fato a se considerar é que a luteína é o carotenoide encontrado no tecido cerebral humano, e apresenta efeitos biológicos que incluem ação antioxidante, anti-inflamatória e estrutural. Estudos relacionam seus teores com melhora do desempenho cognitivo em adultos e crianças, ao aprimorar a função executiva, linguagem, aprendizado, memória e o quociente de inteligência (QI) (Johnson, 2012; Johnson, 2014). Este fato se justifica pela ação da luteína na inibição da formação de radicais livres prejudiciais pela extinção física ou química do oxigênio singlete; indução de alterações na expressão de genes relacionados à inflamação,

diminuição do fator nuclear- $\kappa\beta$ , interleucina-1, e ciclooxygenase; modulação das propriedades funcionais das membranas sinápticas, e aumento da comunicação por junções comunicantes, importantes para o desenvolvimento de circuitos neurais no sistema visual (Johnson, 2014).

Apesar da coloração alaranjada atraente da polpa de *Mauritia vinifera*, foram encontrados poucos estudos que descreveram o perfil de carotenoides neste fruto. Godoy & Rodriguez-Amaya (1994) foram os pioneiros na análise de carotenoides em polpa de *M. vinifera*. Estes pesquisadores relataram a presença de: todo-*trans*- $\beta$ -zeacaroteno ( $5,4 \pm 1,4 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\gamma$ -caroteno ( $36,8 \pm 4,5 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\beta$ -caroteno ( $359,8 \pm 32,5 \mu\text{g.g}^{-1}$ ), 9-*cis*- $\beta$ -caroteno ( $1,0 \pm 0,5 \mu\text{g.g}^{-1}$ ), 13-*cis*- $\beta$ -caroteno ( $4,2 \pm 2,4 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\alpha$ -caroteno ( $80,1 \pm 9,0 \mu\text{g.g}^{-1}$ ), 13-*cis*- $\alpha$ -caroteno ( $1,5 \pm 1,4 \mu\text{g.g}^{-1}$ ), totalizando  $490,8 \mu\text{g.g}^{-1}$ .

Usando métodos mais recentes, Rosso & Mercadante (2007) determinaram mais carotenoides em polpa de *Mauritia vinifera*: fitoeno ( $0,34 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\zeta$ -caroteno ( $0,08 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\gamma$ -caroteno ( $14,76 \mu\text{g.g}^{-1}$ ), *cis*- $\gamma$ -caroteno ( $12,21 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\beta$ -caroteno ( $372,32 \mu\text{g.g}^{-1}$ ), 9-*cis*- $\beta$ -caroteno ( $18,57 \mu\text{g.g}^{-1}$ ), 13-*cis*- $\beta$ -caroteno ( $59,23 \mu\text{g.g}^{-1}$ ), 15-*cis*- $\beta$ -caroteno ( $8,87 \mu\text{g.g}^{-1}$ ), di-*cis*- $\beta$ -caroteno ( $0,11 \mu\text{g.g}^{-1}$ ), 5,6-epoxy- $\beta$ -caroteno ( $0,41 \mu\text{g.g}^{-1}$ ), 5,8-epoxy- $\beta$ -caroteno ( $7,44 \mu\text{g.g}^{-1}$ ), 5,6-epoxy- $\beta$ -criptoxantina ( $0,10 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\delta$ -caroteno ( $2,09 \mu\text{g.g}^{-1}$ ), *cis*- $\delta$ -caroteno ( $11,55 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\alpha$ -caroteno ( $3,23 \mu\text{g.g}^{-1}$ ), todo-*trans*- $\alpha$ -criptoxantina ( $1,28 \mu\text{g.g}^{-1}$ ), di-*cis*- $\alpha$ -caroteno ( $1,25 \mu\text{g.g}^{-1}$ ) e todo-*trans*-luteína ( $0,03 \mu\text{g.g}^{-1}$ ), somando um total de  $513,87 \mu\text{g.g}^{-1}$ .

Cândido et al. (2015) descreveram a presença de luteína, *cis*- $\gamma$ -caroteno, todo-*trans*- $\gamma$ -caroteno, *cis*- $\delta$ -caroteno,  $\alpha$ -caroteno, todo-*trans*- $\beta$ -caroteno e 9-*cis*- $\beta$ -caroteno, embora não tenham quantificado.

Apesar de termos encontrado teores totais de carotenoides em polpa de *M. flexuosa* ( $143,49 \mu\text{g.g}^{-1}$ ) inferiores ao reportado para polpa de *M. vinifera* ( $490$  a  $514 \mu\text{g.g}^{-1}$ ) (Godoy & Rodriguez-Amaya, 1994; Rosso & Mercadante, 2007), o fruto estudado pode ser considerado

fonte de carotenoides, uma vez que esses níveis são considerados muito altos, de acordo com a escala proposta por Britton & Khachik (2009) (baixo: 0-1 µg.g<sup>-1</sup>; moderado: 1-5 µg.g<sup>-1</sup>; alto: 5-20 µg.g<sup>-1</sup>; muito alto: >20 µg.g<sup>-1</sup>).

A polpa de *M. flexuosa* possui teores de β-caroteno (138,78 µg.g<sup>-1</sup>) superiores aos de frutos reconhecidos por apresentarem altos teores de carotenoides, como a acerola (*Malpighia glabra*: 3,4 a 38,0 µg.g<sup>-1</sup>), manga (*Mangifera indica* L.: 2,5 a 18,0 µg.g<sup>-1</sup>), laranja (*Citrus sinensis*, 0,1 a 0,6 µg.g<sup>-1</sup>), papaia (*Carica papaya*: 1,2 a 7,5 µg.g<sup>-1</sup>), e abóbora (*Cucurbita moschata*: 16,0 a 47,0 µg.g<sup>-1</sup>; *Cucurbita maxima*: 15,0 a 21,0 µg.g<sup>-1</sup>) (Rodriguez-Amaya et al., 2008).

Em relação ao valor de vitamina A da polpa de *M. flexuosa* (Tabela 1), deve-se salientar que este possui níveis extremamente relevantes (2.048,4 µg RAE), uma vez que o IOM (*Institute of Medicine, Food and Nutrition Board* - Instituto de Medicina, Conselho de Alimentação e Nutrição) (IOM, 2001) recomenda o consumo diário de 900 µg RAE para homens e 700 µg RAE para mulheres.

### 3.3. Bioacessibilidade de carotenoides

A biodisponibilidade é a fração do nutriente que passa por todo o processo de digestão gastrointestinal, absorção, metabolização, distribuição para os tecidos-alvo e chega à circulação sanguínea. Deste modo, este termo pode ser dividido em bioacessibilidade e bioatividade (Thakur et al., 2020). A bioacessibilidade é definida como a quantidade de um nutriente ingerido que é absorvido e fica disponível para exercer suas funções fisiológicas. Assim, seus teores dependem dos processos envolvidos na digestão, liberação da matriz alimentar, absorção pelas células intestinais e transporte para os tecidos-alvo (Etcheverry, Grusak, & Fleige, 2012). Já a bioatividade compreende os processos envolvidos no transporte e assimilação pelos tecidos-alvo, metabolização e resposta fisiológica (Thakur et al., 2020).

Vários métodos de determinação da bioacessibilidade foram desenvolvidos ao longo dos anos, entretanto é preciso salientar que a bioacessibilidade, que tem ponto final fisiológico ou metabólico, não pode ser medida em sua totalidade pelos métodos *in vitro* (Thakur et al., 2020; Etcheverry, Grusak, & Fleige, 2012). Isso se deve ao fato de fatores fisiológicos e individuais poderem influenciar na absorção dos nutrientes. Fatores tais como: estado nutricional, idade, genótipo, doenças infecciosas crônicas e agudas, secreção de ácido clorídrico e/ou fatores intrínsecos, entre outros, são impossíveis de fatorar em ensaios *in vitro* (Etcheverry, Grusak, & Fleige, 2012). Todavia, os métodos de bioacessibilidade *in vitro* são úteis para fornecer conhecimento sobre possíveis interações entre nutrientes e/ou componentes alimentares, os efeitos de fatores fluentes (incluindo ação das enzimas digestivas), preparação de alimentos e natureza das práticas de processamento da matriz alimentar (Etcheverry, Grusak, & Fleige, 2012).

Durante o amadurecimento do fruto ocorrem profundas transformações associadas ao estado fenológico da planta. Uma das mudanças maiores é a transformação do cloroplasto em cromoplasto. Este processo leva ao desaparecimento de clorofilas e a uma biossíntese de novos carotenoides que não estão presentes no fruto verde (Hornero-Méndez, & Mínguez-Mosquera, 2000). Ademais, é importante salientar que os carotenos geralmente estão associados a proteínas nos cromoplastos, enquanto que as xantofilas se localizam nos cloroplastos (Garrett, et al., 2000). As xantofilas, juntamente com as clorofilas, encontram-se associadas a proteínas de membrana e lipídios. Os carotenoides são liberados para o estroma, onde são pouco solúveis, por isso ocorre a esterificação destes compostos, o que ajuda na sua integração com as membranas (Hornero-Méndez, & Mínguez-Mosquera, 2000).

Condições de processamento dos alimentos (cozimento, microondas e pasteurização), assim como os processos enzimáticos durante a digestão podem quebrar as paredes celulares e romper os complexos de proteínas-carotenoides. Uma vez que estes compostos estejam livres

da matriz alimentar, são incorporados às gotículas lipídicas antes de serem englobadas às micelas. Assim, a presença de lipídios na refeição irá favorecer a absorção dos carotenoides. Por outro lado, a presença de fibra solúveis, fitoesteróis e estanóis provenientes de plantas, podem influenciar negativamente na sua absorção (Etcheverry, Grusak, & Fleige, 2012). A gordura dietética é necessária para a solubilização eficiente de compostos lipofílicos e fitoquímicos, uma vez que os lipídios ajudam na formação e expansão das micelas no estômago, e estimulam a liberação de sais biliares da vesícula biliar (Garrett, et al., 2000).

Cozinhar, resulta em uma liberação mais eficiente dos carotenoides da matriz alimentar auxiliando o encontro dos componentes alimentares com as respectivas enzimas digestivas, de modo a tornar a sua degradação mais eficiente. Este processo resulta em maior liberação de  $\beta$ -caroteno (Hedrén, Mulokozi, & Svanberg, 2002).

É essencial a aplicação de métodos que analisam os carotenoides presentes nas micelas (carotenoides micelarizados prontos para serem absorvidos pelas células intestinais) como medida de bioacessibilidade, uma vez que ao determinar os compostos presentes no quimo há a possibilidade de superestimar a verdadeira bioacessibilidade destes, pois os carotenoides que não são micelarizados permanecem no sobrenadante (Etcheverry, Grusak, & Fleige, 2012; Failla, Chitchumroonchokchai, & Ishida, 2008). Deste modo, os carotenoides micelarizados são obtidos medindo a fração do carotenoide do alimento incorporado nas micelas (obtidas por ultracentrifugação e filtração do componente aquoso).

Ao analisar os resultados do presente trabalho podemos constatar que o processo de digestão simulada *in vitro* influenciou significativamente nos compostos encontrados nas diferentes frações e seus teores. Originalmente, foram identificados nos frutos os seguintes compostos: todo-trans-fitoeno, todo-trans-fitoflueno, cis- $\beta$ -caroteno, e todo-trans- $\beta$ -caroteno; somando um total de 143,49  $\mu\text{g.g}^{-1}$ . No quimo foram identificados todo-trans-luteína, todo-trans-fitoeno, cis-fitoflueno, cis- $\alpha$ -criptoxantina, todo-trans- $\alpha$ -criptoxantina e todo-trans- $\beta$ -

criptoxantina; totalizando  $7,26 \mu\text{g.g}^{-1}$ . Por fim, na fração micelar foi possível apenas a identificação de 5,8-epoxy- $\beta$ -criptoxantina, em concentração de  $0,11 \mu\text{g.g}^{-1}$ , assim apenas 0,077% da concentração total de carotenoides foi determinada na fração micelar. Essa redução tão drástica pode ter sido influenciada pela presença de elevados teores de fibras na polpa (7,2 a  $10,33 \text{ g.100 g}^{-1}$ ) (Berni et al., 2019; Nascimento et al., 2020), que causa a partição de sais biliares e gordura na fase de formação do gel (Van-Het-Hof et al., 2000). Além de diversos compostos que podem prejudicar a transferência de carotenoides da matriz alimentar para as micelas, como o poliéster de sacarose, fitoesterois e estanóis e compostos divalentes (Etcheverry, Grusak, & Fleige, 2012).

Uma vez que foram identificados essencialmente carotenoides em sua conformação *trans*, um aspecto relevante que deve ser discutido é o comportamento diferente entre isômeros, como descrito por Boileau et al. (1999) e Failla, Chitchumroonchokchai, & Ishida (2008), que observaram que os isômeros *cis* do licopeno têm maior probabilidade de serem incorporados em micelas do que sua conformação *trans*, resultando em maior biodisponibilidade dos isômeros *cis*. Ademais, os isômeros *cis*- $\beta$ -caroteno excedem os teores de todo-*trans*- $\beta$ -caroteno durante o processo de formação das micelas, sendo transferidos em maiores teores através da superfície da borda em escova do enterócito (Ferruzzi et al., 2006).

A adesão dos diferentes carotenoides nas micelas dependem de sua polaridade, e consequentemente, lipofilicidade (Etcheverry, Grusak, & Fleige, 2012). A bioacessibilidade de xantofilas é significativamente superior à de carotenos (zeaxantina: 87.6%, luteína: 54.3%,  $\beta$ -criptoxantina: 33.1%,  $\beta$ -caroteno: 6.2%) (O'Sullivan et al., 2010). O mesmo foi descrito por O'Connell, et al. (2008) e Ryan et al. (2008). Após liberação do carotenoide da matriz alimentar, estes devem ser incorporados pelas micelas, todavia, os compostos que permanecem no núcleo da gota de gordura não são transferidos para a micela da mesma maneira que os carotenoides

na superfície da gota. Assim, os carotenóides como a luteína são mais prováveis de serem micelarizados em maior extensão do que o  $\alpha$ -caroteno e o  $\beta$ -caroteno (O'Sullivan et al., 2010).

Por fim, outro fator relevante que pode influenciar na absorção dos carotenoides é a própria interação entre estes compostos a nível intestinal, que competem entre si, causando a redução em sua absorção, ou até mesmo no transporte linfático (Van-Het-Hof et al., 2000).

## Conclusão

A determinação da bioacessibilidade de carotenoides em frutos é considerada um grande desafio atualmente, mas deve-se encorajar o relato das informações encontradas de modo a oferecer subsídio às pesquisas que irão se desenvolver a seguir. Desta forma, é importante relatar que este é pioneiro na realização de digestão *in vitro* nesta matriz alimentar, o que possibilitou a descrição e quantificação dos compostos em quimo e fração micelar.

Os presentes achados indicam que a polpa de *M. flexuosa* apresenta importantes carotenoides, que possuem grande relevância na saúde humana, se destacando a presença de carotenoides provitamina A ( $\beta$ -caroteno,  $\alpha$ -criptoxantina e  $\beta$ -criptoxantina) e o principal carotenóide macular (luteína). Ademais, devemos salientar que a saponificação do extrato se faz necessária, de modo a eliminar a interferência da clorofina, e facilitar a identificação de carotenoides, uma vez que não se observaram ésteres de carotenoides.

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## **Artigo 5**

**Bioacessibilidade de carotenoides de polpa de *Syzygium cumini* e de fruto inteiro de  
*Plinia jaboticaba* (Vell.) Berg após digestão *in vitro***

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**Bioacessibilidade de carotenoides de polpa de *Syzygium cumini* e de fruto inteiro de  
*Plinia jaboticaba* (Vell.) Berg após digestão *in vitro***

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## Resumo

A determinação da fração bioacessível fornece informações valiosas a respeito da dosagem recomendada de cada composto correspondente em sua fonte alimentar, de maneira a garantir a adequada eficácia nutricional. Assim, este trabalho pretende ser pioneiro no estudo de bioacessibilidade de carotenoides de polpa de *S. cumini*, e em fruto inteiro de *P. jaboticaba*. A digestão foi dividida em três fases: oral, gástrica e intestinal, nas quais se controlou temperatura, pH, tempo e agitação, além de simular as condições enzimáticas a que o alimento está exposto. A solução final (quimo) foi separada para extração de carotenoides ou passou por centrifugação, sendo separada a fração micelar, que também foi utilizada para extração de carotenoides, que foram extraídos com

metanol. Observou-se que a polpa de *S. cumini* possui carotenoides provitamina A ( $\alpha$ -caroteno,  $\beta$ -caroteno e  $\beta$ -zeacaroteno) e o principal carotenoide macular (luteína), além de exibir bioacessibilidade total de 9,30% destes compostos. Comportamento similar foi observado para fruto inteiro de *P. jaboticaba*, que se destacou pelos teores de luteína e  $\beta$ -caroteno, e exibiu bioacessibilidade de 21,36% do teor total de carotenoides.

**Palavras-chave:** APCI, Alimentos Funcionais, Composição Proximal, Espectrometria de Massa, Nutrientes.

## Abstract

The determination of the bioaccessible fraction provides valuable information regarding the recommended dosage of each corresponding compound in its food source, in order to ensure adequate nutritional efficacy. Thus, this work intends to be a pioneer in the study of carotenoids bioaccessibility in *S. cumini* pulp, and in whole fruit of *P. jaboticaba*. Digestion was divided into three phases: oral, gastric and intestinal, in which temperature, pH, time and agitation were controlled, in addition to simulating the enzymatic conditions to which the food is exposed. The final solution (chyme) was separated to extract carotenoids or underwent centrifugation, separating the micellar fraction, which was also used to extract carotenoids, which were extracted with methanol. It was observed that the pulp of *S. cumini* has provitamin A carotenoids ( $\alpha$ -carotene,  $\beta$ -carotene and  $\beta$ -zeacarotene) and the main macular carotenoid (lutein), in addition to exhibiting total bioaccessibility of 9.30% of these compounds. A similar behavior was observed for the whole fruit of *P. jaboticaba*, which stood out for its lutein and  $\beta$ -carotene contents, and exhibited a bioaccessibility of 21.36% of the total carotenoid content.

**Keywords:** APCI, Functional food, Proximate Composition, Mass spectrometry, Nutrients.

## **1. Introdução**

Os compostos bioativos podem ser categorizados de acordo com as classes químicas, sendo divididos em glicosídeos, flavonóides, proantocianinas, taninos, terpenos, resinas, ligninas, alcalóides, peptídeos, proteínas, dentre outros (Bernhoft, 2010). Os carotenoides são tetraterpenos com duplas ligações conjugadas. Divididos em carotenos e xantofilas, estes compostos são pigmentos lipossolúveis amplamente difundidos no reino vegetal, sendo responsáveis, principalmente, pelas cores amarela, vermelha e laranja (Maoka, 2019). Sua função principal está relacionada com a captação de luz e extinção de radicais livres. Muitos destes compostos podem ser absorvidos e armazenados em tecidos animais (Bernhoft, 2010). A luteína e a zeaxantina, por exemplo, se acumulam na mácula humana, servindo de filtro à passagem da luz azul, o licopeno pode ser encontrado na próstata de humanos e o  $\beta$ -caroteno no tecido epitelial (Bernhoft, 2010; Ma et al., 2012). No entanto, alguns compostos não ficam disponíveis para absorção, ao serem degradados pela acidez estomacal, como anteraxantina, neoxantina, violaxantina e epoxy luteína (Maoka, 2019). Os carotenóides mais discutidos e estudados são aqueles que podem ser úteis na síntese de vitamina A, como  $\beta$ -caroteno,  $\alpha$ -caroteno e  $\beta$ -criptoxantina (Bernhoft, 2010; Maoka, 2019).

Deste modo, para que estes compostos forneçam seus benefícios ao organismo humano é necessário que estejam biodisponíveis, sendo efetivamente absorvidos pelo intestino e migrem através da corrente sanguínea, chegando aos tecidos-alvos. A biodisponibilidade compreende os mecanismos de digestão e absorção gastrointestinais, a migração através da parede intestinal, e a circulação sanguínea. Além disso, este termo pode ser dividido em outros dois termos: bioacessibilidade e bioatividade. A bioacessibilidade engloba a separação do composto da matriz alimentar, as

transformações digestivas, a absorção intestinal e o metabolismo pré-sistêmico. Por outro lado, a bioatividade corresponde ao transporte e assimilação pelos tecidos-alvos, metabolismo e resposta fisiológica (Thakur et al., 2020).

A digestão humana é um mecanismo complexo que envolve muitas etapas, através das quais o alimento sofre diversas transformações até que o nutriente seja completamente hidrolisado e libere seus monômeros, que ficarão disponíveis para absorção. A matriz alimentar sofre sua fragmentação, sobretudo, na boca e estômago, enquanto a digestão enzimática e absorção de nutrientes ocorrem no intestino delgado (Guerra et al., 2012). Assim, a determinação da fração bioacessível fornece informações valiosas a respeito da dosagem recomendada de cada composto e a fonte alimentar correspondente, de maneira a garantir a adequada eficácia nutricional (Fernández-García et al., 2009).

O jambolão (*Syzygium cumini*) é um fruto nativo da Ásia, mas que se disseminou por todo o globo, podendo ser encontrado na África e América Latina, uma vez que se adapta bem a climas tropicais e subtropicais (Sabino et al., 2018). A polpa de jambolão é amplamente conhecida pela presença de teores consideráveis de antocianinas, que podem variar entre 28,5 e 1318,4 mg.100 g<sup>-1</sup>, dependendo do estágio de maturação e região de procedência (Lestario et al., 2017). Deste modo, o fruto se destaca pelos teores significativos de compostos fenólicos (995 a 1117 mg AGE.100 g<sup>-1</sup>) (Reynertson et al., 2008; Rufino et al., 2010), principalmente os ácidos gálico e elágico (Lestario et al., 2017). Teores moderados de carotenoides foram descritos na porção comestível de *S. cumini* (8,92 µg.g<sup>-1</sup>), porém poucos estudos descrevem seu perfil de carotenoides, além de terem identificado poucos compostos e não analisado a sua bioacessibilidade (Nascimento-Silva et al., 2022).

Fruto da mesma família e espécie do jambolão, a jabuticaba, destaca-se pelos elevados teores de compostos fenólicos totais ( $744 \text{ mg AGE.100 g}^{-1}$ ), principalmente ácido elágico ( $311 \text{ mg AGE.100 g}^{-1}$ ) (Abe et al., 2011; Salomão et al., 2018). O fruto possui teores moderados de carotenoides  $8,73 \mu\text{g.g}^{-1}$  (Inada et al., 2015). Todavia, poucos estudos que descrevem o perfil de carotenoides nesta matriz alimentar foram encontrados, estes identificaram apenas  $\beta$ -caroteno e luteína, e nenhum avaliou a bioacessibilidade destes compostos (Biazotto et al., 2019; Inada et al., 2015).

Portanto, optou-se por trabalhar com tais frutos uma vez que se destacam nos teores de compostos bioativos, além de terem sido encontrados poucos ou nenhum estudo com o mesmo propósito. Assim, este trabalho pretende ser pioneiro no estudo de bioacessibilidade de carotenoides em polpa de *S. cumini*, e em fruto inteiro de *P. jaboticaba*. Esses dados podem servir de subsídio para aumentar o valor agregado aos frutos, valorizá-los como alimentos funcionais, expandir o seu consumo e ter consequências diretas na segurança econômica e alimentar das populações locais envolvidas na sua coleta e distribuição.

## 2. Material e métodos

### 2.1. Amostras

Frutos completamente maduros de jambolão (*Syzygium cumini*) em Dezembro e jabuticaba (*Plinia jaboticaba*, variedade Sabará) em Novembro de 2019, em Caldazinha – Goiás, Brazil ( $16^{\circ}45'58.8''\text{S}$ ,  $48^{\circ}55'04.9''\text{W}$ ). Os frutos foram coletados durante o período de safra, sendo selecionados de acordo com o ponto ótimo de maturação e suas condições morfológicas. Assim, foram selecionados os frutos íntegros com coloração mais intensa (roxo escuro, mais próximo a preto), livres de deformidades ou micro-

organismos. Os frutos foram sanitizados com hipoclorito de sódio (2 ppm) e armazenados à temperatura ambiente até despolpamento. A polpa comestível (epicarpo e mesocarpo) de *S. cumini* foi manualmente separada da semente com faca inox, enquanto que a *P. jaboticaba* foi triturada inteira em liquidificador com copo de vidro e haste inox. Optou-se por analisar o fruto inteiro de *P. jaboticaba* (epicarpo, mesocarpo e semente), uma vez que industrialmente é a forma mais utilizada. Por fim, as amostras foram embaladas a vácuo em sacos de polietileno de baixa densidade protegidos da luz, e armazenadas até o momento das análises sob congelamento a -20 °C.

## 2.2. Composição proximal

Os teores de umidade (método nº 934.06) e cinzas (método nº 940.26) da polpa de buriti foram obtidos por gravimetria após secagem da amostra a 105 °C e incineração a 550 °C até peso constante, respectivamente (AOAC, 2019).

Para determinar os valores de proteína bruta, foi utilizado o método micro-Kjeldahl (AOAC, 2019 - método nº 920.152), que determina a matéria total de nitrogênio na amostra. 0,2 g de amostra é digerido com 1,0 g de 5,0 mL de ácido sulfúrico PA e mistura de catalisador a 350 °C, e então o nitrogênio da amostra é destilado e coletado em um erlenmeyer contendo 10,0 mL de ácido bórico e 3 gotas de indicador de Andersen. Em seguida, o destilado é titulado com uma solução de ácido clorídrico (0,02 mol/L), sendo convertido em proteína, utilizando o fator de conversão 6,25.

O conteúdo lipídico total foi determinado seguindo a metodologia descrita por Bligh & Dyer (1959). De acordo com o qual, 3,0 g de amostra foram homogeneizados com 10,0 ml de clorofórmio, 20,0 ml de metanol e 8,0 ml de água em agitador rotativo por 30 min. Em seguida, 10,0 mL de clorofórmio e 10,0 mL de sulfato de sódio (1,5%) foram adicionados à amostra, que foi agitada vigorosamente por 2 min. A solução foi

armazenada à temperatura ambiente durante 12 horas. Após a separação, a fase aquosa foi descartada e a camada inferior foi filtrada em papel filme e coletada em placa de Petri. O solvente foi evaporado em uma capela e o teor de lipídios foi determinado por diferença de peso.

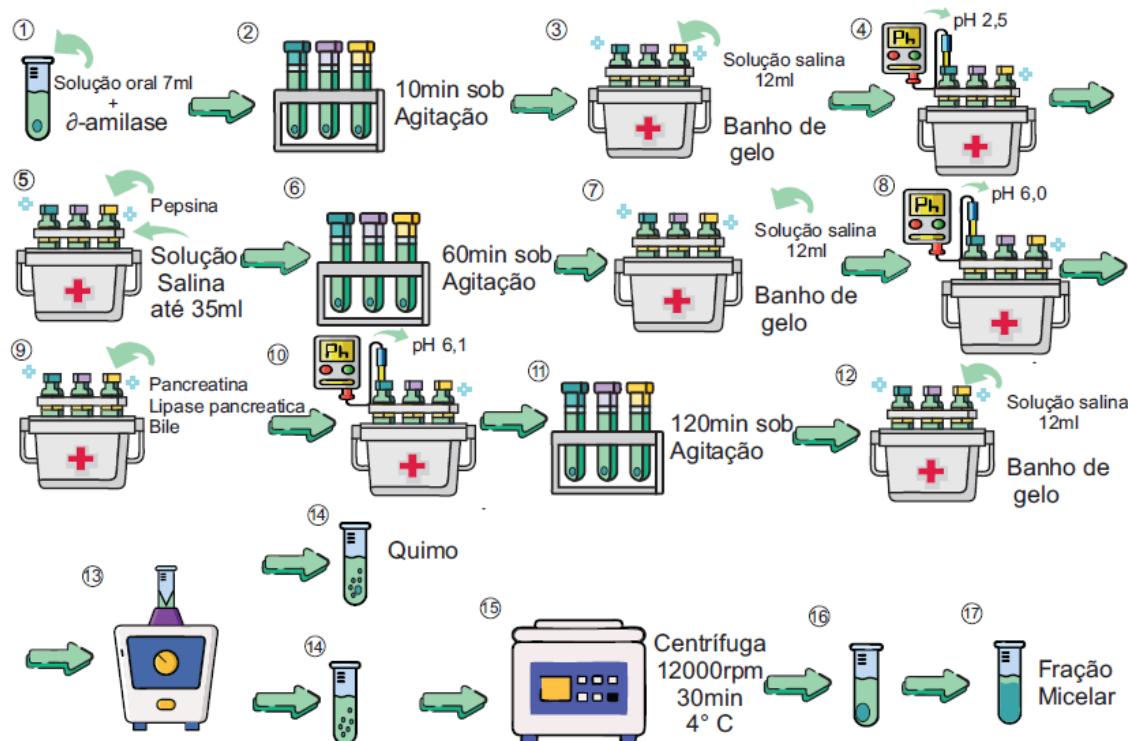
O teor de carboidratos totais foi estimado por diferença, subtraindo-se os valores de umidade, proteína bruta, cinzas e lipídios de 100. O valor energético total das amostras foi calculado com os seguintes fatores de conversão: 4,0 kcal/g de proteína e carboidratos totais e 9,0 kcal/g de lipídios (Merril, Watt, 1973).

### *2.3. Bioacessibilidade in vitro*

A digestão *in vitro* foi realizada de acordo com o proposto por Rodrigues et al. (2017), com modificações (Fig. 1). A digestão foi dividida em três fases: oral, gástrica e intestinal. Inicialmente se pesou 1,0 g de amostra em tubo de vidro, ao qual foi adicionada solução salivar salina (NaCl, KCl, CaCl<sub>2</sub>, ureia, ácido úrico, mucina e α-amilase). Esta solução foi submetida a aquecimento (37 °C) por 10 minutos sob agitação (85 rpm). Ao final do tempo, o pH da solução foi corrigido para 2,5 e iniciou-se a fase gástrica, na qual, solução contendo pepsina e solução salina (NaCl, KCl, CaCl<sub>2</sub>) foram adicionadas ao tubo. Este foi mantido em aquecimento (37 °C) por 60 minutos sob agitação (85 rpm). Em seguida, iniciou-se a fase intestinal corrigindo o pH para 6,0 e se acrescentou solução pancreática (pancreatina e lipase pancreática) e solução biliar. A solução foi mantida sob aquecimento (37 °C) por 120 minutos sob agitação (85 rpm). Por fim, a solução final (quimo) foi separada para extração de carotenoides ou passou por centrifugação, sendo separada a fração micelar, que também foi utilizada para extração de carotenoides.

A percentagem de fração bioacessível foi calculada de acordo com a equação a seguir:

$$\% \text{ Bioacessibilidade} = \left( \frac{\text{Concentração de carotenoides na micela}}{\text{Concentração de carotenoides na polpa do fruto}} \right) \times 100$$



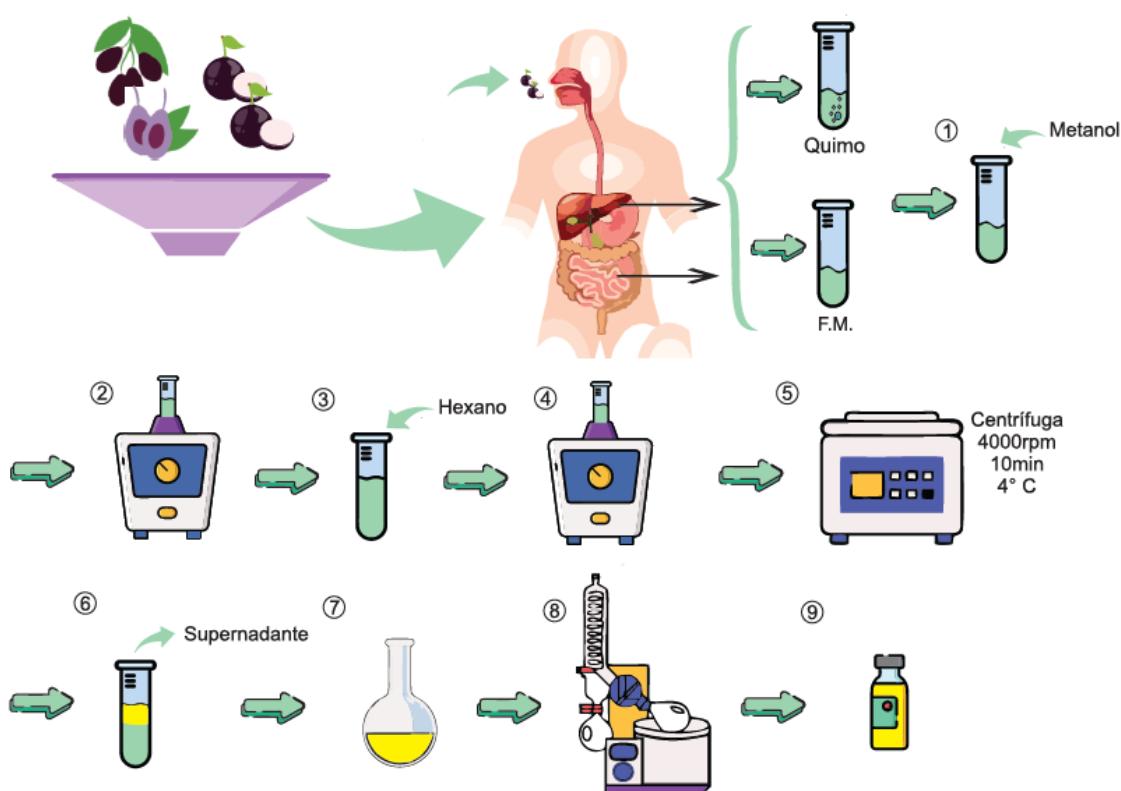
**Fig. 1.** Bioacessibilidade *in vitro* segundo Rodrigues et al. (2017), com modificações.

#### 2.4. Extração de carotenoides

Os carotenoides da polpa de *S. cumini* e fruto inteiro de *P. jaboticaba*, assim como do quimo e da fração micelar foram extraídos de acordo com o sugerido por Rodrigues et al. (2017), com modificações (Fig. 2). Resumidamente, adicionou-se 10 mL de metanol à amostra e se submeteu o tubo de vidro a agitação em vórtex por 1 minuto. Em seguida, acrescentou-se 5 mL de hexano, e mais uma vez o tubo foi submetido a vórtex po 1 minuto. Por fim, o tubo foi centrifugado (4000 rpm a 4 °C por 10 minutos) e o sobrenadante foi coletado e transferido para balão de fundo redondo. O processo se repetiu exaustivamente até que não fosse possível observar qualquer coloração no

solvente. Ao final do processo, o extrato foi seco em evaporador rotativo e armazenado a -80 °C até o momento das análises.

É importante salientar que as amostras não foram saponificadas, de modo a permitir a identificação de ésteres de carotenoides, caso houvessem.



**Fig. 2.** Extração de carotenoides segundo Rodrigues et al. (2017), com modificações.

## 2.5 Separação e identificação de carotenoides em HPLC-DAD-MS/MS

Para a análise dos carotenoides foram aplicadas as condições cromatográficas e de espectrometria de massas utilizadas por Murador et al. (2019). A separação dos compostos foi conduzida em coluna C30 YMC (5 µm, 250 x 4,6 mm d.i.) (Waters, Wilmington, NC, EUA). O equipamento utilizado para a separação e identificação dos carotenoides foi o HPLC (*High Performance Liquid Cromatography* - Cromatógrafo Líquido de Alta Eficiência) (Shimadzu, Quioto, Japão). O equipamento possui autoinjetor (SIL-20A), bomba binária (LC-20AD), desgaseificador (DGU-20A3R), e está acoplado

em série aos detectores de arranjo de diodos (DAD) (Shimadzu, SPD-M20A) e de massas (LCMS 2020), que possui analisador de massa *single-quadrupole* e fonte de ionização APCI (*atmospheric pressure chemical ionization* - ionização química de pressão atmosférica).

Para realização da corrida cromatográfica se aplicou um gradiente linear com metanol (MeOH), éter metil terc-butílico (MTBE) e água (H<sub>2</sub>O) ultrapura, compondo, desta forma, as fases móveis A (MeOH/MTBE/H<sub>2</sub>O, 81:15:4) e B (MeOH/MTBE/H<sub>2</sub>O, 16:80:4). O gradiente foi desenvolvido da seguinte forma: 100% fase A durante 20 minutos, alterando para 0% fase A em 120 minutos, retornando para 100% fase A em 1 minuto, mantendo-se nesta condição por mais 10 minutos. A vazão foi de 0,8 mL/min, volume de injeção variável, com temperatura da coluna mantida a 35°C. Espectros UV-visíveis foram adquiridos entre 220 e 700 nm e os cromatogramas foram processados a 450 nm, 347 nm (para fitoflueno) e 286 nm (para fitoeno).

Os espectros de massas foram obtidos utilizando interface APCI nos modos positivo e negativo; detector de voltagem de 1.05 kV; temperatura da interface em 350 °C; temperatura DL e do bloco de calor de 300 °C; fluxo do gás de nebulização (N<sub>2</sub>) de 2,0 L/min; fluxo do gás de secagem (N<sub>2</sub>) de 5,0 L/min. Estes espectros foram obtidos na faixa de razão carga/massa (*m/z*) de 300 a 1200.

Para realizar a identificação dos carotenoides e dos ésteres de carotenoides presentes na polpa de *M. flexuosa* e frações após digestão *in vitro* foram utilizados os dados da eluição cromatográfica em coluna C<sub>30</sub> e as características dos espectros UV-visível ( $\lambda_{\text{max}}$ , estrutura fina espectral e intensidade do pico cis), e de massas (molécula protonada ([M+H]<sup>+</sup>) e fragmentos *in source*, além de realização de co-cromatografia utilizando padrões e ainda a comparação com dados consistentes da literatura (Azevedo-Meleiro & Rodriguez-Amaya, 2004; Britton, 2004; Rivera et al., (2013); Rosso &

Mercadante, 2007; Breemen et al., 2012). Para confirmação da identidade dos carotenoides e quantificação dos mesmos, foram utilizadas curvas de calibração com padrões de (todo-E)-luteína, (todo-E)-zeaxantina, (todo-E)- $\alpha$ -caroteno, (todo-E)- $\beta$ -caroteno, (todo-E)- $\beta$ -criptoxantina, (todo-E)-licopeno. O teor total de carotenóides foi calculado como a soma dos conteúdos de cada carotenóide individual separados na coluna C<sub>30</sub>.

Para o cálculo do teor de Equivalente de Atividade de Retinol (*Retinol Activity Equivalent - RAE*), multiplicou-se o conteúdo de carotenoides por 12  $\mu\text{g}$  (todo-trans- $\beta$ -caroteno) e 24  $\mu\text{g}$  (outros carotenoides provitamina A –  $\alpha$ -caroteno e  $\beta$ -criptoxantina) (IOM, 2001).

### **3. Resultados e discussão**

#### *3.1. Composição proximal*

Ambos os frutos se destacam pelos elevados teores de água e concentrações significativas de açúcares (Tabela 1). A polpa de *S. cumini* analisada neste estudo possui teores similares ao reportado por Brito et al. (2017) (87,2 g.100 g<sup>-1</sup>), Seraglio et al. (2018) (84,7 a 88,6 g.100 g<sup>-1</sup>), e Vital et al. (2020) (84,0 a 85,3 g.100 g<sup>-1</sup>), que analisaram *S. cumini* provenientes dos Estados Pará, Santa Catarina e Minas Gerais, respectivamente. Fruto inteiro de *P. jaboticaba* apresentou teores similares ao reportado por Inada et al. (2015) (87,4 g.100 g<sup>-1</sup>) e Lima et al. (2008) (79,41 g.100 g<sup>-1</sup>) para *M. jaboticaba* (cv. Sabará). Ao compararmos os frutos deste trabalho com frutos com características parecidas, como jussara (*Euterpe edulis*) (76,6 g.100 g<sup>-1</sup>) e açaí (*Euterpe oleracea*) (82,7 a 92,0 g.100 g<sup>-1</sup>), podemos notar que os teores de umidade são similares (Inada et al., 2015, Minighin et al., 2020).

**Tabela 1.**

Nutrientes ( $\text{g.}100\text{ g}^{-1}$ ) e valor energético total (VET, em Kcal) em polpa de *S. cumini* e fruto inteiro de *P. jaboticaba*, base úmida.

Fruto	Umidade	Cinzas	Proteína	Lipídeos	Carboidratos	VET
<i>S. cumini</i>	$88,9^{\text{a}} \pm 0,2$	$0,4^{\text{a}} \pm 0,0$	$0,9^{\text{a}} \pm 0,0$	$0,3^{\text{a}} \pm 0,0$	$9,5^{\text{b}} \pm 0,2$	$44,2^{\text{b}} \pm 0,7$
<i>P. jaboticaba</i>	$85,6^{\text{b}} \pm 0,1$	$0,4^{\text{a}} \pm 0,0$	$0,8^{\text{b}} \pm 0,0$	$0,2^{\text{b}} \pm 0,0$	$13,0^{\text{a}} \pm 0,2$	$57,1^{\text{a}} \pm 0,4$

\* Resultados expressos como média  $\pm$  desvio padrão de três repetições. Letras diferentes na mesma coluna indicam diferença estatística ( $p$ -valor  $<0,05$ ).

Se tratando dos teores de cinzas, não se observou diferença estatística entre os frutos analisados no presente estudo (Tabela 1). As concentrações de cinzas totais foram superiores ao reportado para as polpas de jambolão descritas por Brito et al. (2017) ( $0,23\text{ g.}100\text{ g}^{-1}$ ) e Vital et al. (2020) ( $0,32\text{ g.}100\text{ g}^{-1}$ ), mas similares ao descrito por Barcia et al. (2012) ( $0,42\text{ g.}100\text{ g}^{-1}$ ). Inada et al. (2015) relatou teores similares ( $0,39\text{ g.}100\text{ g}^{-1}$ ) ao observado para *P. jaboticaba*. Além disso, podemos observar que os frutos descritos neste estudo possuem concentrações de cinzas inferiores às polpas de jussara ( $1,2\text{ g.}100\text{ g}^{-1}$ ) (Inada et al., 2015) e açaí ( $0,42$  a  $0,94\text{ g.}100\text{ g}^{-1}$ ) (Minighin et al., 2020).

A polpa de *S. cumini* possui teores estatisticamente mais elevados de proteína do que fruto inteiro de *P. jaboticaba*, mas ambos apresentam valores inferiores à jussara ( $2,4\text{ g.}100\text{ g}^{-1}$ ) (Inada et al., 2015) e ao açaí ( $1,12$  a  $1,51\text{ g.}100\text{ g}^{-1}$ ) (Minighin et al., 2020). Concentrações similares foram reportadas para *S. cumini* por Brito et al. (2017) ( $0,85\text{ g.}100\text{ g}^{-1}$ ) e Vital et al. (2020) ( $0,75\text{ g.}100\text{ g}^{-1}$ ), e para *P. jaboticaba* ( $0,63\text{ g.}100\text{ g}^{-1}$ ) por Inada et al. (2015).

Ambos os frutos analisados no presente estudo (Tabela 1) apresentam teores baixos de lipídeos, sendo inferiores ao reportado para jussara ( $3,32\text{ g.}100\text{ g}^{-1}$ ) (Inada et al., 2015) e açaí ( $2,94$  a  $10,67\text{ g.}100\text{ g}^{-1}$ ) (Minighin et al., 2020). Vital et al. (2020) reportou concentrações similares para *S. cumini* ( $0,27\text{ g.}100\text{ g}^{-1}$ ), todavia Brito et al. (2017) descreveu teores maiores ( $0,49\text{ g.}100\text{ g}^{-1}$ ). Fruto inteiro de *P. jaboticaba* analisada

por Inada et al. (2015) possui concentrações de lipídeos ( $0,23 \text{ g.}100 \text{ g}^{-1}$ ) similares ao observado no presente estudo.

O fruto inteiro de *P. jaboticaba* tem concentrações de carboidratos totais superior ao observado para *S. cumini*, mas ambos possuem teores inferiores à jussara ( $41,22 \text{ g.}100\text{g}^{-1}$ , base úmida) (Inada et al., 2015) e superiores ao açaí (2,88 a  $5,24 \text{ g.}100 \text{ g}^{-1}$ ) (Minighin et al., 2020). Valores próximos foram descritos por Brito et al. (2017) para *S. cumini* ( $11,4 \text{ g.}100 \text{ g}^{-1}$ ) e por Inada et al. (2015) para *P. jaboticaba* ( $11,35 \text{ g.}100 \text{ g}^{-1}$ ).

Uma vez que a *P. jaboticaba* apresentou teores superiores de proteínas e carboidratos, isso refletiu no teor energético total, que, também, foi superior ao da polpa de *S. cumini*. Todavia, ambos os frutos tiveram resultados inferiores à jussara ( $66,0 \text{ Kcal.}100 \text{ g}^{-1}$ ). Resultados similares para *S. cumini* foram descritos por Brito et al. (2017) ( $48,0 \text{ Kcal.}100 \text{ g}$ ), e superiores por Barcia et al. (2012) (61 a  $68 \text{ Kcal.}100 \text{ g}^{-1}$ ). Fruto inteiro de *S. cumini* descrito por Inada et al. (2015) possui valor energético total ( $31 \text{ Kcal.}100 \text{ g}^{-1}$ ) inferior ao reportado neste estudo (Tabela 1).

### 3.2. Perfil de carotenoides em polpa de *S. cumini* e fruto inteiro de *P. jaboticaba* antes e após digestão *in vitro*

Os compostos identificados em todas as frações analisadas (fruto, quimo e fração micelar) estão detalhados nas Tabelas 3 e 4, e sua identificação descrita a seguir.

Muitos dos picos majoritários determinados ambos os frutos corresponderam à clorofila (de acordo com Chen & Chen, 1992), uma vez que não foi realizada a etapa de saponificação. A saponificação é utilizada para remoção de clorofilas e lipídios indesejados, que podem interferir na separação cromatográfica (Rodriguez-Amaya, 2001). Todavia, como o objetivo do presente trabalho era identificar a presença de ésteres de carotenoides, caso houvessem, não foi realizada saponificação. A maioria dos

compostos identificados em fruto inteiro de *P. jaboticaba* (Tabela 2) são isômeros todo-*trans*, assim como acontece na maioria dos alimentos descritos na literatura (Vélez, 2016).

Os compostos foram identificados como todo-*trans*-luteína ao compararmos os achados do UV-vis (% III/II e  $\lambda_{\max}$ ) com a literatura científica (Breemen et al., 2012; Crupi et al., 2010; Rosso & Mercadante, 2007), além de termos confirmado sua massa molar ( $569 \text{ g.mol}^{-1}$ ). Este composto se difere da zeaxantina unicamente pela posição da dupla ligação entre carbonos do anel- $\epsilon$ , mas descarta-se este composto pelo  $\lambda_{\max}$  identificado no UV-vis, além da presença do fragmento  $495 \text{ m/z}$ , que é formado pela perda de água na molécula protonada seguida pela fragmentação do anel  $\epsilon$ -ionona (Breemen et al., 2012). Compostos que possuem anel  $\epsilon$ -ionona nos grupos terminais eluem antes dos compostos com anel  $\beta$ -ionona, além de absorverem luz em menores comprimentos de onda (Vélez, 2016).

O carotenoide todo-*trans*-neoxantina foi tentativamente identificado ao apresentar UV-vis ( $\lambda_{\max}$ ) e ordem de eluição na coluna C<sub>30</sub> correspondente ao descrito na literatura (Crupi et al., 2010; Rivera et al., 2013; Rosso & Mercadante, 2007). Este composto é muito parecido com a violaxantina, podendo ser diferenciado com auxílio da fragmentação no espectro de massas (Mercadante et al., 1997).

Todo-*trans*- $\alpha$ -caroteno foi identificado pelo UV-vis (% III/II e  $\lambda_{\max}$ ) e  $t_R$  correspondentes. Além disso, observou-se fragmentação típica da molécula ao observar os seguintes fragmentos: 481 [M + H – 56] e 409, que indicam a perda de anéis  $\alpha$ -ionona, provenientes da fragmentação retro-Diels-Alder. O fragmento mais abundante é o 537  $m/z$ , indicando ser essa a massa molar do composto.

Comportamento similar, foi observado ao analisar o espectro do todo-*trans*- $\beta$ -caroteno, uma vez que o fragmento mais abundante no espectro de massa da molécula protonada foi o 553  $m/z$ , e os fragmentos identificados 481 [M + H – 56] e 409 sugerem

fragmentação dos anéis  $\beta$ -ionona. Além disso, estes compostos apresentaram UV-vis (% III/II e  $\lambda_{\max}$ ) ordem de eluição na coluna C<sub>30</sub> correspondente ao descrito na literatura (Crupi et al., 2010; Rivera et al., 2013; Rosso & Mercadante, 2007). Apesar dos isômeros *trans* serem mais distribuídos na natureza, ao sofrer a ação de calor, luz, oxigênio e certas reações químicas, as duplas ligações podem isomerizar da forma *trans* para mono- ou poli-*cis* (Vélez, 2016). Desta forma, ao comparar os resultados obtidos neste estudo com a literatura científica (Breemen et al., 2012; Rosso & Mercadante, 2007), foi tentativamente identificado o carotenoide 9-*cis*- $\beta$ -caroteno, ao se constatar a presença de um pico a 333 nm. Segundo Vélez (2016), os carotenoides em isomeria *cis* absorvem luz em comprimentos de onda inferiores, apresentam coeficiente de absorção menores e perda de estrutura fina. Carotenoides mono-*cis* absorvem luz em comprimento de onda máximo apenas entre 2 a 6 nm abaixo de seu isômero *trans*, todavia os isômeros di-*cis* absorvem em comprimento de onda bem mais baixo. Outros fatores relevantes são o aparecimento de um novo pico de comprimento de onda entre 330 e 350 nm, e a alteração no tempo de retenção, uma vez que o tempo diminui em fase estacionária de coluna C<sub>30</sub> em detrimento da posição mais central da dupla ligação *cis* (Vélez, 2016).

Além disso, o composto 10'-apo- $\beta$ -caroteno-10'-ol, também foi tentativamente identificado levando-se em consideração a literatura científica (Rivera et al., 2013; Rosso & Mercadante, 2007). O termo "apocarotenoide" é usado para se referir a qualquer composto derivado da clivagem de carotenoides, através da qual o esqueleto de carbono foi encurtado pela remoção de fragmentos de uma extremidade ou de ambas as extremidades por meios enzimáticos ou não enzimáticos (Meléndez-Martínez, 2019).

Todo-*trans*-fitoeno foi identificado a 286 nm, enquanto que o carotenoide todo-*trans*-fitoflueno a 347 nm. Observou-se que o UV-vis ( $\lambda_{\max}$ ) e o tempo de eluição na coluna C<sub>30</sub> correspondiam ao esperado (Crupi et al., 2010; Rivera et al., 2013; Rosso &

Mercadante, 2007). O fitoeno e o fitoflueno são carotenoides cílicos incolores, assim apresentam comportamento diferente dos demais, o que dificulta sua identificação (Rodrigues et al., 2016; Vélez, 2016).

Após a digestão *in vitro* do fruto inteiro e *P. jaboticaba*, identificou-se o carotenoide *cis*- $\alpha$ -criptoxantina, uma vez que se constatou fragmentação típica do composto (535 [M + H – 18]) com liberação de moléculas de água. Ademais, a fragmentação demonstra maior intensidade do pico 535 *m/z* em comparação ao 553 *m/z*, o que diferencia a  $\alpha$ -criptoxantina da zeinoxantina (Rosso & Mercadante, 2007). O UV-vis (% III/II e  $\lambda_{max}$ ) corresponde ao descrito na literatura científica (Crupi et al., 2010; Rivera et al., 2013; Rosso & Mercadante, 2007).

5,6-epoxy- $\alpha$ -caroteno foram tentativamente identificados em quimo de *P. jaboticaba* através da análise de seu UV-vis ( $\lambda_{max}$ ), tempo de retenção e fragmentação. A identificação de epoxy carotenoides tem ganhado a atenção de pesquisadores, uma vez que podem fornecer importantes informações sobre condições de armazenamento e processamento dos alimentos, além de apresentarem aplicações farmacêuticas (Vélez, 2016). Carotenoides com grupos epoxy absorvem luz em maiores comprimentos de onda máximos do que aqueles que apresentam grupos furanoide, devido ao encurtamento do cromóforo, causado pela dupla ligação conjugada (Vélez, 2016).

Por fim, o *cis*- $\gamma$ -caroteno foi identificado na fração micelar de fruto inteiro de *P. jaboticaba* ao comparar-se seus resultados com a literatura. A presença do fragmento 467 *m/z* [M + H – 69] foi crucial para esse achado, uma vez que indica a eliminação do grupo  $\psi$ -final (Rivera et al., 2013). É muito comum coeluição deste carotenoide com outros (Rosso & Mercadante, 2007). Provavelmente, por esse motivo não foi possível sua identificação no fruto ou quimo. Este é um carotenoide com reconhecida função pró-

vitamina A, uma vez que apresenta o anel  $\beta$ -ionona em uma de suas terminações (Breemen et al., 2012).

A polpa de *S. cumini* ( $0,86 \mu\text{g} \cdot \text{g}^{-1}$ ) e o fruto inteiro de *P. jaboticaba* ( $2,06 \mu\text{g} \cdot \text{g}^{-1}$ ) possuem teores totais de carotenoides similares a de outros frutos da mesma família, como os frutos descritos por Farias et al. (2020): *Syzygium cumini* ( $0,9 \mu\text{g} \cdot \text{g}^{-1}$ ), *Syzygium malaccense* ( $0,01$  a  $3,93 \mu\text{g} \cdot \text{g}^{-1}$ ), *Eugenia pyriformis* ( $2,07$  a  $2,56 \mu\text{g} \cdot \text{g}^{-1}$ ), e *Campomanesia xanthocarpa* ( $3,22$  a  $7,22 \mu\text{g} \cdot \text{g}^{-1}$ ). De acordo com a escala proposta por Britton & Khachik (2009) (baixo:  $0-1 \mu\text{g} \cdot \text{g}^{-1}$ ; moderado:  $1-5 \mu\text{g} \cdot \text{g}^{-1}$ ; alto:  $5-20 \mu\text{g} \cdot \text{g}^{-1}$ ; muito alto:  $>20 \mu\text{g} \cdot \text{g}^{-1}$ ), a polpa de *S. cumini* possui teores baixos, enquanto que o fruto inteiro de *P. jaboticaba* apresenta teores moderados de carotenoides (Tabela 3).

Como já esperado, por pertencerem à família Myrtaceae (Mercadante et al., 2017), polpa de *S. cumini* e o fruto inteiro de *P. jaboticaba* se destacam pela presença de luteína (*S. cumini*:  $0,3 \mu\text{g} \cdot \text{g}^{-1}$ , 35% do teor total de carotenoides do fruto; *P. jaboticaba*:  $0,96 \mu\text{g} \cdot \text{g}^{-1}$ , correspondendo a 47%). Este é um carotenoide com reconhecidos benefícios à saúde humana, desempenhando papel promissor como fator de proteção contra distúrbios neurológicos, doenças oculares, irritação da pele, complicações cardíacas, infecções microbianas e cárries ósseas (Mitra et al., 2021). A luteína é conhecida por eliminar eficazmente espécies reativas de oxigênio (ERO's), especialmente oxigênio singlet e radicais peroxil. Para isso, a luteína sai de seu estado fundamental e interage com o oxigênio singlet, recebendo energia, o que leva à formação de oxigênio em estado fundamental e luteína excitada triplet. A energia da luteína no estado triplet é então prontamente dissipada para o ambiente circundante, resultando em luteína intacta para reutilização (Tsao et al., 2007).

Segundo Nascimento-Silva et al. (2022) apenas dois estudos descreveram o perfil e teores de carotenoides em *S. cumini* (Faria et al., 2011; Barcia et al., 2012). Barcia et al.

(2012) identificaram a presença de todo-*trans*-criptoxantina e uma mistura de luteína e zeaxantina. Por outro lado, Faria et al. (2011) identificaram os seguintes compostos: *cis*-neoxantina/*cis*-violaxantina ( $0,006 \mu\text{g}.\text{g}^{-1}$ ), *cis*-luteína ( $0,02 \mu\text{g}.\text{g}^{-1}$ ), todo-*trans*-luteína ( $0,39 \mu\text{g}.\text{g}^{-1}$ ), todo-*trans*-zeaxantina ( $0,017 \mu\text{g}.\text{g}^{-1}$ ), fitoeno ( $0,056 \mu\text{g}.\text{g}^{-1}$ ), 15-*cis*- $\beta$ -caroteno ( $0,003 \mu\text{g}.\text{g}^{-1}$ ), 13-*cis*- $\beta$ -caroteno ( $0,029 \mu\text{g}.\text{g}^{-1}$ ), todo-*trans*- $\alpha$ -caroteno ( $0,031 \mu\text{g}.\text{g}^{-1}$ ), todo-*trans*- $\beta$ -caroteno ( $0,227 \mu\text{g}.\text{g}^{-1}$ ), e 9-*cis*- $\beta$ -caroteno ( $0,049 \mu\text{g}.\text{g}^{-1}$ ).

Foram encontrados na literatura científica poucos estudos que descreveram o perfil de carotenoides em jaboticaba. Inada et al. (2015) relataram que o  $\beta$ -caroteno foi o único carotenoide possível de se identificar e quantificar na polpa de *M. jaboticaba* ( $8,73 \mu\text{g}.\text{g}^{-1}$ , matéria úmida;  $0,73 \mu\text{g.RAE}$ ). Entretanto, Biazotto et al. (2019), que analisaram epicarpo e mesocarpo de *P. cauliflora*, relataram teores de (todo-E)-luteína ( $0,82$  a  $1,72 \mu\text{g}.\text{g}^{-1}$ ) e (todo-E)- $\beta$ -caroteno ( $0,33$  a  $0,99 \mu\text{g}.\text{g}^{-1}$ ) similares ao presente estudo. Deste modo, este é o primeiro trabalho a identificar neoxantina,  $\alpha$ -caroteno, 9-*cis*- $\beta$ -caroteno, fitoeno e fitoflueno em *P. jaboticaba*.

Contudo, muitos fatores podem influenciar no conteúdo de carotenoides em frutos e vegetais. Dentre estes, destacam-se o tipo de produto, cultivar/variedade, clima, condições edáficas, maturação, estágio de desenvolvimento, tecnologias pós-colheita (temperatura de armazenamento, atmosfera controlada/modificada, tratamentos térmicos), processamento, condições agrotecnológicas, entre outros (Yahia et al., 2018).

**Tabela 2.**

Tempo de retenção ( $t_R$ ) em coluna C<sub>30</sub>, UV-visível (% III/II; % A<sub>B</sub>/II;  $\lambda_{max}$ ) e espectroscopia de massa encontrados em polpa de *S. cumini* (fruto e fração micelar) em HPLC-DAD-MS/MS.

Carotenoide	$t_R$ (min)	% III/II	% A <sub>B</sub> /II	$\lambda_{max}$ (nm) <sup>1</sup>	[M + H] <sup>+</sup> <i>m/z</i>	Fragmentação dos íons ( <i>m/z</i> )	Teor de carotenoides ( $\mu\text{g} \cdot \text{g}^{-1}$ amostra fresca)
<i>Fruto</i>							
Fitoeno	26,8	14,3		/, 275, 285		nd	0,13 ± 0,07
Todo- <i>trans</i> -luteína	14,118 a 16,08	57	5	327, / 455, 473	569	551 [M + H -18], 533 [M + H -18 -18], 527, 509 [M + H -18], 495 [M + H -18 -56], 481, 463 [M + H -106]	0,14 ± 0,06
<i>Cis</i> -luteína <sup>2</sup>	17,8			347, 412, /, 472		nd	0,16
<i>Cis</i> - $\alpha$ -caroteno	21,5 a 22,85			347, /, 436	537	481 [M + H -56]	0,10 ± 0,02
Di- <i>cis</i> - $\beta$ -caroteno <sup>2</sup>	31 a 32			356, 407, 445, 458	537	481 [M + H -56]	0,03 ± 0,01
15- <i>cis</i> - $\beta$ -caroteno <sup>2</sup>	27,9 a 33,8			333, 424, 440, /	537	481 [M + H -56]	0,15
Todo- <i>trans</i> - $\beta$ -caroteno	37 a 37,4	25	8	/, 452, 479	537	481 [M + H -56], 467, 465, 409 [M + H -56]	0,12 ± 0,03
9- <i>cis</i> - $\beta$ -caroteno	38,97			406, 424, 445		nd	0,03
<b>TOTAL</b>							<b>0,86</b>
<b>RAE</b>							<b>6,36 µg RAE</b>
<i>Fração micelar</i>							
Todo- <i>trans</i> - $\beta$ -zeacaroteno <sup>2</sup>	47,4 a 48,3			407, 424, /	nd	nd	0,04 ± 0,01
9- <i>cis</i> - $\beta$ -caroteno	48 a 53			304, 423, 443, 466	nd	nd	0,03 ± 0,02
Fitoeno	53,8			268, 280, 304	nd	nd	0,01 ± 0,0
<b>TOTAL</b>							<b>0,08</b>
<b>RAE</b>							<b>0,84 µg RAE</b>
<b>Bioacessibilidade</b>							<b>9,30 %</b>

Valores apresentados em média ± desvio padrão. <sup>1</sup>Comprimento de onda máximo em gradiente linear de metanol/MTBE. <sup>2</sup>Tentativa de identificação. **RAE:** Retinol Activity Equivalent (Equivalente de Atividade de Retinol).

**Tabela 3.**

Tempo de retenção ( $t_R$ ) em coluna C<sub>30</sub>, UV-visível (% III/II; % A<sub>B</sub>/II;  $\lambda_{max}$ ) e espectroscopia de massa encontrados em fruto inteiro de *P. jaboticaba* (fruto, quimo e fração micelar) em HPLC-DAD-MS/MS.

Carotenoide	$t_R$ (min)	% III/II	% A <sub>B</sub> /II	$\lambda_{max}$ (nm) <sup>1</sup>	[M + H] <sup>+</sup> <i>m/z</i>	Fragmentação dos íons ( <i>m/z</i> )	Teor de carotenoides ( $\mu\text{g} \cdot \text{g}^{-1}$ amostra fresca)
<i>Fruto</i>							
Fitoeno	6,18			286	nd	nd	0,12
Fitoeno	9,21			290	nd	nd	0,22
Todo- <i>trans</i> -luteína <sup>2</sup>	9,20 – 10,17			404, 467, -	569	495 [M + H – 18 – 56]	0,96 ± 0,37
Todo- <i>trans</i> -neoxantina <sup>2</sup>	11,07	50	37	321, 420, 441, 466	nd	nd	0,02
Todo- <i>trans</i> - $\alpha$ -caroteno	25,44	62	0	337, 424, 445, 474	537	527, 509 [M + H – 18], 449, 481 [M + H – 56], 467, 465, 409 [M + H – 56]	0,18 ± 0,05
Todo- <i>trans</i> - $\beta$ -caroteno	28,33	20		-, 452, 479	537	525, 511, 509 [M + H – 18], 497, 481 [M + H – 56], 467, 465, 409 [M + H – 56]	0,46 ± 0,16
9- <i>cis</i> - $\beta$ -caroteno	30,06	17	4	333, -, 446, 468	537	509 [M + H – 18], 481 [M + H – 56]	0,10 ± 0,03
<b>TOTAL RAE</b>							<b>2,06</b> <b>11,04 µg RAE</b>
<i>Quimo</i>							
10'-apo- $\beta$ -caroteno-10'-ol <sup>2</sup>	7,46	83,33		-, 401, 426	nd	nd	0,02
Cis- $\alpha$ -criptoxantina	9,00	57,14	12,5	337, -, 445, 473	553	535 [M + H – 18], 521, 509 [M + H – 18], 497, 481 [M + H – 56], 467	0,44 ± 0,05
Cis-fitoflueno <sup>2</sup>	12,25 – 13,47			373, 382	nd	nd	0,39
5,6-epoxy- $\alpha$ -caroteno	21,62 – 22,55			416, 436, -	553	535 [M + H – 18], 509 [M + H – 18], 481 [M + H – 56], 465	0,04 ± 0,00
Cis- $\alpha$ -caroteno	10,48		50	324, 407, 426, 446	537	531, 509 [M + H – 18], 481 [M + H – 56], 444 [M + H – 92]	0,04 ± 0,00
Todo- <i>trans</i> - $\alpha$ -caroteno	29,21	33,33	12,5	416, 445, 485	537	527, 509 [M + H – 18], 495, 481 [M + H – 56], 467, 465	0,06
<b>TOTAL RAE</b>							<b>0,99</b> <b>14,16 µg RAE</b>
<i>Fração micelar</i>							
Todo- <i>trans</i> -luteína <sup>2</sup>	6,99 – 7,64	71,43		417, 446, 474	nd	nd	0,01 ± 0,00
Fitoeno	6,92 – 7,64			204, 264, 272-86	nd	nd	0,09
Fitoflueno <sup>2</sup>	9,7 – 10,6	42,86		-, 320, 339	nd	nd	0,01
Cis- $\gamma$ -caroteno	47,80 – 48,38			398, 424, -	537	467 [M + H – 69]	0,33 ± 0,33
<b>TOTAL RAE</b>							<b>0,44</b> <b>7,92 µg RAE</b>
<b>Bioacessibilidade</b>							<b>21,36%</b>

Valores apresentados em média ± desvio padrão. <sup>1</sup>Comprimento de onda máximo em gradiente linear de metanol/MTBE. <sup>2</sup>Tentativa de identificação. **RAE:** Retinol Activity Equivalent (Equivalente de Atividade de Retinol).

### 3.4. Bioacessibilidade de carotenoides

O efeito biológico dos carotenoides é determinado por fatores que envolvem todo o processo de absorção, transporte e armazenamento nos tecidos-alvo. Deste modo, a bioacessibilidade destes compostos é um fator crucial para a garantia de sua eficácia, uma vez que pode limitar a chegada de seu conteúdo (Yahia et al., 2018).

Por serem compostos lipofílicos, os carotenoides devem ser liberados da matriz alimentar, solubilizados em gotículas de emulsão lipídica, micelarizados em micelas mistas de sais biliares para que, então, possam ser absorvidos pelos enterócitos e empacotados em quilomícrons para secreção nos tecidos-alvo (Mercadante et al., 2017). O processo inicia na boca, na qual a mastigação libera os compostos da matriz alimentar, que migram para o estômago. No estômago, os complexos caroteno-proteína são dissociados pela ação da pepsina. Digestão adicional ocorre no intestino delgado por enzimas proteolíticas. Uma vez que os carotenoides são liberados no estômago, eles se associam aos lipídios da dieta, ao serem emulsionados pelos sais biliares (Priyadarshani, 2015). Os enterócitos absorvem os carotenoides através de difusão simples ou facilitada. Então, estes serão transportados por vesículas de fosfolipídeos pelas células do intestino (Yahia et al., 2018).

Ao analisar os resultados do presente estudo, podemos relatar que o processo de digestão *in vitro* evidenciou redução significativa nos teores totais de carotenoides para ambos os frutos. Deste modo, a fração bioacessível de carotenoides em polpa de *S. cumini* é 9,30%, sendo que observa-se manutenção dos teores de 9-*cis*-β-caroteno (**bioacessibilidade = 100%**) e redução da concentração de fitoeno (**bioacessibilidade = 7,69%**). Além disso, os carotenoides todo-*trans*-luteína, *cis*-luteína, *cis*-α-caroteno, di-*cis*-β-caroteno, e todo-*trans*-β-caroteno não foram identificados na fração micelar (Tabela 2).

A respeito do fruto inteiro de *P. jaboticaba*, nota-se bioacessibilidade de 21,36% do teor total de carotenoides, sendo que os teores de todo-*trans*-luteína (Bioacessibilidade =

1,04%) e fitoeno (Bioacessibilidade = 26,47%) reduziram. Contudo, foram identificados dois novos carotenoides na fração micelar: *cis*- $\gamma$ -caroteno e fitoflueno (Tabela 3).

Estudos indicam que o processo digestivo causa a formação de ketocarotenoides ao sofrer reações de oxidação, redução e migração de duplas ligações. As alterações estruturais mais comuns após digestão são isomerização de *trans* para *cis*, epoxidação e degradação (Yahia et al., 2018). O que justifica a alteração no perfil dos compostos identificados no presente estudo (Tabelas 2 e 3). O diéster de luteína é cerca de 60% mais biodisponível do que a luteína livre, apesar do fato de que os diésteres de luteína necessitarem de serem hidrolisados em luteína livre no lúmen intestinal ou no enterócito (Mercadante et al., 2017). Os isômeros 13-*cis* e 9-*cis* do  $\beta$ -caroteno são mais eficientemente incorporados às micelas, enterócitos e quilomicrons do que o todo-*trans*- $\beta$ -caroteno (Yahia et al., 2018). Contudo, a conversão das formas isoméricas 9-*cis* e 13-*cis* do  $\beta$ -caroteno em vitamina A representam apenas 38 e 62%, respectivamente, do teor de conversão do isômero todo-*trans* (Priyadarshani, 2015). Poucas informações a respeito da absorção de epóxidos estão disponíveis na literatura científica, mas alguns trabalhos sugerem que estes isômeros não são absorvidos pelo organismo humano (Priyadarshani, 2015; Yahia et al., 2018). A neoxantina dietética é convertida em estereoisômeros (R/S) do neocromo pela acidez intragástrica antes da absorção (Yahia et al., 2018).

Os carotenos apresentam bioacessibilidade inferior às xantofilas, uma vez que estas últimas se beneficiam pela possibilidade de esterificação (Priyadarshani, 2015; Thakur et al., 2020). A bioacessibilidade de  $\beta$ -criptoxantina e  $\beta$ -caroteno varia de 0,02% a 9,8% e 0,1% a 9,1%, respectivamente, em diferentes frutos. A bioacessibilidade de  $\alpha$ -caroteno é ainda menor, variando entre 0% e 4,6% (Estévez-Santiago et al., 2016). Enquanto que a bioacessibilidade luteína pode variar entre 55 e 160% e de zeaxantina entre 24 e 388%, em batatas (Thakur et al., 2020). Entretanto, a diferença na resposta plasmática relativa entre a luteína e o  $\beta$ -caroteno não

reflete as diferenças na capacidade de absorção. Isso se deve à bioconversão do β-caroteno em retinol e seus derivados, algo que não ocorre com a luteína (Priyadarshani, 2015).

Além disso, outros nutrientes podem interferir no teor de compostos que ficarão bioacessíveis, tanto positivamente quanto negativamente. Os lipídeos da dieta afetam positivamente a bioacessibilidade de carotenoides, ao estimular a secreção de ácidos biliares, proporcionar um ambiente hidrofóbico e promover a formação das micelas (Priyadarshani, 2015). Por outro lado, as fibras solúveis interferem negativamente, pois atrapalham a formação das micelas e interferem no contato da micela com as células da mucosa intestinal, de modo a aumentar a viscosidade do conteúdo intestinal, e, consequentemente, aumentar a excreção fecal destes compostos (Priyadarshani, 2015; Thakur et al., 2020).

A polpa de jambolão possui teores de fibra dietética, que podem variar entre 0,11 e 0,90 g.100 g<sup>-1</sup>, possuindo 0,65 g.100 g<sup>-1</sup> de pectina (Nascimento-Silva et al., 2022), enquanto que o fruto inteiro de jabuticaba apresenta teores de fibras solúveis que variam de 1,80 a 3,57 g.100 g<sup>-1</sup> e de fibras insolúveis de 7,90 a 17,00 g.100 g<sup>-1</sup> (Alezandro et al., 2013; Gurak et al., 2014; Lima et al., 2008), possuindo 0,62 g.100 g<sup>-1</sup> de pectina (Becker et al., 2015; Vieites et al., 2011).

## Conclusão

A determinação da bioacessibilidade de carotenoides em frutos é considerada um grande desafio atualmente, mas deve-se encorajar o relato das informações encontradas de modo a oferecer subsídio às pesquisas que irão se desenvolver a seguir. Desta forma, é importante relatar que este trabalho foi pioneiro na realização de digestão *in vitro* em polpa de *S. cumini* e fruto inteiro de *P. jaboticaba*, o que possibilitou a descrição e quantificação dos compostos em quimo e fração micelar.

Os presentes achados indicam que a polpa de *S. cumini* apresenta importantes carotenoides, que possuem grande relevância na saúde humana, se destacando a presença de carotenoides provitamina A ( $\alpha$ -caroteno,  $\beta$ -caroteno e  $\beta$ -zeacaroteno) e o principal carotenoide macular (luteína), além de exibir bioacessibilidade total de 9,30% destes compostos. Comportamento similar foi observado para fruto inteiro de *P. jaboticaba*, que se destacou pelos teores de luteína e  $\beta$ -caroteno, e apresentou bioacessibilidade de 21,36% do teor total de carotenoides. Ademais, recomenda-se a saponificação do extrato, uma vez que não se observaram ésteres de carotenoides.

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## **CONSIDERAÇÕES FINAIS**

Esta tese é pioneira no estudo de bioacessibilidade do perfil de carotenoides após digestão *in vitro* em polpa de *Mauritia flexuosa* e *Syzygium cumini* e fruto inteiro de *Plinia jaboticaba*, sendo o primeiro trabalho a realizar tal tipo de metodologia no Centro-Oeste do Brasil. Perante isso, é importante ressaltar que vários problemas foram superados para chegarmos a este momento, visto que enfrentamos um período ímpar de incertezas com a pandemia de COVID-19, que levou à impossibilidade de acesso aos laboratórios, corte de recursos financeiros, morosidade de instalação e manutenção de diversos equipamentos, além de escassez de matéria-prima. Deste modo, as parcerias realizadas com a Faculdade de Nutrição da Universidade Federal de Goiás (UFG) e o Programa de Pós-Graduação em Nutrição Humana da Universidade de Brasília (UNB) foram primordiais para a conclusão desta tese e resposta ao questionamento inicial.

Para embasamento teórico do problema iniciou-se o estudo através de revisões da literatura científica (CAPÍTULO I), que demandaram muito tempo e dedicação, porém foram necessárias para a fundamentação das análises realizadas e direcionamento dos problemas e lacunas a respeito do tema principal. Assim, foram elaboradas três revisões da literatura, cujos métodos de pesquisa foram sendo aprimorados à medida que os artigos foram escritos.

O artigo 1 (Nutritiononal properties of buriti (*Mauritia genus*) and Health benefits) destacou a importância do fruto de *Mauritia flexuosa*, ao descrever seu valor nutricional e efeito na saúde humana, demonstrando que pode ser considerado excelente fonte de magnésio, já que 100 g do fruto pode oferecer entre 204 e 565% da RDA, elevado teor e o perfil dos tocoferóis, presença de fitoesteróis em níveis representativos e teores de carotenoides, principalmente β-caroteno, elevados. Entretanto, poucos estudos descrevem e quantificam o perfil de carotenoides nesta matriz alimentar, e nenhum estudo a respeito de sua bioacessibilidade foi identificado.

O segundo artigo (Jambolan (*Syzygium cumini* (L.) Skeels): A review on its nutrients, bioactive compounds and health benefits) comprovou que *S. cumini* é fonte de antocianinas, principalmente delphinidina, petunidina, malvidina e peonidina, que possuem reconhecida ação antioxidante. Apesar de terem sido encontrados poucos estudos que descreveram o teor e perfil de carotenoides no fruto, este trabalho foi o primeiro a propor uma possível via para a biossíntese desses compostos.

O artigo 3 (Bioactive compounds of jaboticaba (*Plinia* sp.): A Systematic Review) destacou que a jaboticaba inteira se destaca pelos altos teores de polifenóis totais (1196,5 a 2031,1 mg GAE.100 g<sup>-1</sup>), principalmente antocianinas (cianidina e delphinidina), ácido elágico, ácido metilelágico, ácido gálico, miricetina, queracetina, castalagina, pedunculagina e vescalagina. Ao avaliar o comportamento desses compostos após a digestão *in vitro*, observou-se que as antocianinas não sofreram tanto nas fases salivar e gástrica, mas apresentaram redução significativa após a fase intestinal. Já os elagitaninos e galotaninos apresentaram grande degradação (-44%) logo no primeiro estágio. Assim como a miricetina, a queracetina e seus derivados, que reduzem em todas as fases (salivar: -43,4%; gástrico: -53,5%; intestinal: -59,5%). Após a digestão gástrica, foi relatada uma redução significativa nos taninos hidrolisáveis (-58,2% para -97,5%), mas a hidrólise desses compostos refletiu em aumento nos teores de ácidos gálico e elágico (+820%; +60,9%). Além disso, destacou-se que *Plinia* sp. possui níveis moderados de carotenoides (1,52 e 3,27 µg.g<sup>-1</sup>), mas poucos estudos foram encontrados a respeito do perfil desses compostos.

Então, esse estudo nos leva ao próximo capítulo (CAPÍTULO II), que foi dividido em dois artigos nos quais relata-se a metodologia escolhida para a determinação bioacessibilidade do perfil de carotenoides após digestão *in vitro* em polpa de *Mauritia flexuosa* e *Syzygium cumini* e fruto inteiro de *P. jaboticaba*. Em ambas pesquisas, a digestão foi dividida em três fases: oral, gástrica e intestinal, nas quais se controlou temperatura, pH, tempo e agitação, além de simular as condições enzimáticas a que o alimento está exposto. A solução final (quimo) foi separada para extração de carotenoides ou passou por centrifugação, sendo separada a fração micelar, que também foi utilizada para extração de carotenoides em metanol.

O artigo 4 (Bioacessibilidade de carotenoides em *M. flexuosa* por digestão *in vitro*) possibilitou a conclusão de que a digestão simulada *in vitro* influencia significativamente nos teores totais de carotenoides de polpa de *M. flexuosa*. Originalmente, foram identificados nos frutos os seguintes compostos: todo-*trans*-fitoeno, todo-*trans*-fitofluen, *cis*-β-caroteno, todo-*trans*-β-caroteno e todo-*trans*-β-carotene; somando um total de 143,49 µg.g<sup>-1</sup>. No quimo foram identificados todo-*trans*-luteína, todo-*trans*-fitoeno, *cis*-fitoflueno, *cis*-α-criptoxantina, todo-*trans*-α-criptoxantina e todo-*trans*-β-criptoxantina; totalizando 7,26 µg.g<sup>-1</sup>. Por fim, na fração micelar foi possível apenas a identificação de 5,8-epoxy-β-criptoxantina, em concentração de 0,11

$\mu\text{g}\cdot\text{g}^{-1}$ , assim apenas 0,077% do total de carotenoides ficam bioacessíveis após a digestão simulada.

Por fim, no artigo 5 (Bioacessibilidade de carotenoides em polpa de *Syzygium cumini* e fruto inteiro de *Plinia jaboticaba* (Vell.) Berg por digestão *in vitro*) foi possível constatar que o processo de digestão *in vitro* evidenciou redução significativa nos teores totais de carotenoides para ambos os frutos. Deste modo, a fração bioacessível de carotenoides em polpa de *S. cumini* é 9,30%, sendo que observa-se um aumento de todo-*trans*- $\beta$ -caroteno (bioacessibilidade = 133,33%), e redução de 15-*cis*- $\beta$ -caroteno (bioacessibilidade = 20%) e fitoeno (bioacessibilidade = 7,69%). Além disso, os carotenoides todo-*trans*-luteína, *cis*-luteína, *cis*- $\alpha$ -caroteno, di-*cis*- $\beta$ -caroteno, e todo-*trans*- $\beta$ -caroteno não foram identificados na fração micelar. A respeito do fruto inteiro de *P. jaboticaba*, nota-se bioacessibilidade de 21,36% do teor total de carotenoides, sendo que os teores de todo-*trans*-luteína (Bioacessibilidade = 1,04%) e fitoeno (Bioacessibilidade = 26,47%) reduziram. Contudo, foram identificados dois novos carotenoides na fração micelar: *cis*- $\gamma$ -caroteno e fitoflueno.

Deste modo, foi possível respondermos ao nosso problema de pesquisa e discutir o efeito da digestão no perfil e teor de carotenoides em polpa de *M. flexuosa* e *S. cumini* e fruto inteiro de *P. jaboticaba*. Entretanto, por se tratar de uma pesquisa inovadora, sugerem-se mais análises que descrevam diferentes interações e processos que possam aumentar a bioacessibilidade dos carotenoides nestes frutos, de modo a ter uma compreensão ampla de seu comportamento e aprimorar a discussão do tema.