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ANDRÉA ALVES SEIXAS LIMA

CAMBUCI (*Campomanesia phaea*): UM ESTUDO ABRANGENTE DE SUA COMPOSIÇÃO

SALVADOR
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Dissertação apresentada ao Programa de Pós-Graduação em Ciência de Alimentos (PGAli) da Universidade Federal da Bahia, como requisito parcial para a obtenção do título de Mestre em Ciência de Alimentos.

Prof. Dr. Deborah Murowaniecki Otero
Orientador

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A Comissão Julgadora dos trabalhos de defesa de Dissertação de Mestrado do(a) candidato(a) ***Andréa Alves Seixas Lima***, em sessão pública realizada em 26 /09/2024.

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Salvador, 26 de setembro de 2024.

Dedico este trabalho,

À minha mãe (Vera Maria), aos meus irmãos Alex e Ernani, aos meus amigos, colegas e professores, por toda dedicação e amor oferecidos ao longo dessa jornada.

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Folha de epigrafe

"*O solo, a água e a biodiversidade são as bases da produção de alimentos. Quando os destruímos, destruímos a nossa capacidade de nos alimentarmos*."

Vandana Shiva

RESUMO

O cambuci (*Campomanesia phaea*) é um fruto nativo da Mata Atlântica, pertencente à família Myrtaceae, e atualmente classificado como uma planta alimentícia não convencional (PANC). Caracteriza-se por sua polpa de odor essencialmente adocicado e sabor ácido, que lembra o limão. Este fruto singular não é apenas interessante do ponto de vista gastronômico, mas também apresenta propriedades nutricionais e bioativas notáveis, que o tornam um candidato promissor para aplicações industriais e alimentares. No entanto, sua árvore está em risco de extinção devido ao desmatamento generalizado, o que sublinha a necessidade urgente de conservação e uso sustentável. O cambuci apresenta um rendimento elevado, variando entre 91,8% e 92,4%, e uma alta umidade de 86,04%, o que o torna suculento. Com um pH ácido de 2,96, o fruto é rico em compostos bioativos, destacando-se os compostos fenólicos, que atingem 545,3 mg.g^{-1} GAE, carotenoides (9,17 mg de β-caroteno.g^{-1}) e clorofila (41,79 mg.g^{-1}). Os compostos fenólicos, em particular, estão presentes em maiores quantidades do que em muitas frutas convencionais, o que potencializa os benefícios antioxidantes do cambuci. A atividade antioxidante do cambuci foi medida por métodos como ABTS e FRAP, utilizando extratos aquosos e etanólicos. No método ABTS, a atividade antioxidante atingiu 326,25 mmol Trolox.g^{-1} em extratos etanólicos e 275,15 mmol Trolox.g^{-1} em extratos aquosos. Pelo método FRAP, os valores foram de 162,4 μmol Fe^{+}.g^{-1} em etanol e 251 μmol Fe^{+}.g^{-1} em água. Esses resultados indicam uma significativa capacidade antioxidante, com os extratos etanólicos mostrando maior eficácia. Além disso, a composição volátil do cambuci revelou uma riqueza de aromas frescos e cítricos, predominantemente da classe dos terpenos, que são conhecidos por suas propriedades aromáticas e medicinais. Novos compostos também foram identificados, ampliando o entendimento sobre o perfil volátil desta fruta. Apesar das suas qualidades nutricionais e bioativas, como o alto teor de ácido ascórbico, que confere propriedades antioxidantes e anti-inflamatórias, o cambuci ainda é pouco consumido. Sua riqueza em compostos antioxidantes, como os carotenoides e polifenóis (especialmente flavonoides e proantocianidinas), destaca seu potencial para a saúde humana, beneficiando o sistema imunológico e apresentando atividades antialérgicas. Contudo, a exploração madeireira e a falta de consumo colocam a árvore de cambuci em risco de extinção. Este estudo enfatiza o potencial do cambuci como uma fruta com aplicações promissoras na indústria alimentícia. Suas propriedades físico-químicas favorecem a utilização do fruto em diferentes produtos, promovendo uma alimentação saudável e diversificada. Além disso, o incentivo ao consumo e cultivo sustentável do cambuci pode contribuir para a preservação ambiental e a geração de renda para comunidades locais. Portanto, a inclusão do cambuci na rotina alimentar e sua valorização industrial podem não só enriquecer a dieta humana, mas também promover a sustentabilidade e conservação da biodiversidade.

Palavras-chave*: Plantas Alimentícias Não Convencionais; Mata Atlântica, Compostos Bioativos; Mrytaceae*

ABSTRACT

Cambuci (*Campomanesia phaea*) is a fruit native to the Atlantic Forest, belonging to the Myrtaceae family, and currently classified as a non-conventional food plant (NCFP). It is characterized by its pulp with an essentially sweet odor and acidic flavor, reminiscent of lemon. This unique fruit is not only interesting from a gastronomic point of view, but also has remarkable nutritional and bioactive properties, which make it a promising candidate for industrial and food applications. However, its tree is at risk of extinction due to widespread deforestation, which highlights the urgent need for conservation and sustainable use. Cambuci has a high yield, ranging from 91.8% to 92.4%, and a high humidity of 86.04%, which makes it juicy. With an acidic pH of 2.96, the fruit is rich in bioactive compounds, with emphasis on phenolic compounds, which reach 545.3 $mg.g^{-1}$ GAE, carotenoids (9.17 mg of β-carotene.g^{-1}) and chlorophyll (41.79 $mg.g^{-1}$). Phenolic compounds, in particular, are present in greater quantities than in many conventional fruits, which enhances the antioxidant benefits of cambuci. The antioxidant activity of cambuci was measured by methods such as ABTS and FRAP, using aqueous and ethanolic extracts. In the ABTS method, the antioxidant activity reached 326.25 mmol Trolox.g^{-1} in ethanolic extracts and 275.15 mmol Trolox.g^{-1} in aqueous extracts. Using the FRAP method, the values were 162.4 μmol $Fe^{+}.g^{-1}$ in ethanol and 251 μmol $Fe^{+}.g^{-1}$ in water. These results indicate a significant antioxidant capacity, with ethanolic extracts showing greater efficacy. In addition, the volatile composition of cambuci revealed a wealth of fresh and citrus aromas, predominantly from the terpene class, which are known for their aromatic and medicinal properties. New compounds were also identified, expanding the understanding of the volatile profile of this fruit. Despite its nutritional and bioactive qualities, such as the high content of ascorbic acid, which confers antioxidant and anti-inflammatory properties, cambuci is still little consumed. Its richness in antioxidant compounds, such as carotenoids and polyphenols (especially flavonoids and proanthocyanidins), highlights its potential for human health, benefiting the immune system and presenting anti-allergic activities. However, logging and lack of consumption put the cambuci tree at risk of extinction. This study highlights the potential of cambuci as a fruit with promising applications in the food industry. Its physical and chemical properties favor the use of the fruit in different products, promoting a healthy and diversified diet. In addition, encouraging the consumption and sustainable cultivation of cambuci can contribute to environmental preservation and income generation for local communities. Therefore, including cambuci in the daily diet and its industrial valorization can not only enrich the human diet, but also promote sustainability and biodiversity conservation.

Keywords*: Unconventional Food Plants; Atlantic Forest, Bioactive Compounds; Mrytaceae*.

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LISTA DE ABREVIATURAS E SIGLAS

PANC	Plantas Alimentícias Não Convencionais
IUCN	International Union for the Conservation of Nature and Natural Resources
NCDs	Non-Communicable Chronic Diseases
DPPH	2-difenil-1-picrilhidrazil
ABTS	2,2´-azinobis (3-etilbenzotiazolina-6-sulfonic acid)
FRAP	Ferric Reducing Antioxidant Power
ORAC	Oxygen Radical Absorbance Capacity
PMS	Phenazine Methosulfate
DHR	Diidrorodamina 123
DAF-2	Diaminofluoresceína-2;
GAE	Gallic Acid Equivalents
Cya-chlor	Cyanidin-3-O-rutinoside chloride
CE	Catechins Equivalents

SUMÁRIO

Capítulo I

Cambuci (Campomanesia Phaea)- Myrtacea: Um Estudo Abrangente de sua Composição Nutricional e Bioativa

1. INTRODUÇÃO

O Brasil, atualmente o terceiro maior produtor de frutas do mundo, possui uma produção agrícola majoritariamente focada em frutas convencionais como banana, laranja, uva, abacaxi, maçã e melancia, sendo que apenas o abacaxi é uma fruta nativa (Taver et al., 2022). Contudo, a vasta biodiversidade vegetal do Brasil, oferece um potencial significativo para a exploração de outras espécies nativas subutilizadas, em termos de suas propriedades nutricionais e farmacológicas (Lorençoni et al., 2020).

A *Campomanesia phaea*, popularmente conhecida como cambuci, camoti, ubucambuci, camuci, ou camocim é uma fruta advinda da árvore cambucizeiro (Lamarca et al., 2024; Bianchini et al., 2020). Endêmica do Brasil, do bioma Mata Atlântica e de vegetação de floresta pluvial ou ombrófila, é encontrada principalmente na região sudeste, em Minas Gerais, Rio de Janeiro e São Paulo (Santoro et al., 2022; Oliveira et al.,2023)

As propriedades nutricionais do cambuci destacam-se pela presença significativa de compostos bioativos, o que lhe confere também um grande potencial antioxidante (Donado-Pestana et al., 2018). Estudos têm revelado sua riqueza em fenólicos, antioxidantes e vitamina C, todos componentes essenciais para uma alimentação saudável (Stafussa et al., 2021; Taver et al., 2022; Dias et al., 2018).

O uso tradicional do cambuci é um aspecto cultural significativo em algumas regiões do Brasil, especialmente no estado de São Paulo, onde o fruto é utilizado em diversas preparações caseiras (Silva et al., 2020). Ao longo do tempo, seu uso foi diminuindo devido à urbanização e à substituição por frutas mais comerciais, sendo levada até ao risco de extinção (Dias et al., 2018). Recentemente, há um movimento de resgate dessas tradições, impulsionado pelo crescente interesse em Plantas Alimentícias Não Convencionais (PANCs) e em alimentos mais naturais (dos Santos Conceição et al., 2023; Tuler et al., 2019). Feiras gastronômicas, restaurantes e festivais, como a Rota do Cambuci, produzido pelo Instituto Auá, têm redescoberto o cambuci, promovendo receitas modernas que combinam técnicas tradicionais com novos métodos de preparo (Instituto Auá, 2024). Esse resgate cultural, além de valorizar o patrimônio local, abre espaço para a redescoberta de sabores autênticos e a valorização da biodiversidade brasileira.

O consumo limitado do cambuci, também está atrelado a falta de pesquisas sobre suas diversas propriedades. Apesar de produtos derivados do fruto, como geleias, licores, sorvetes e cosméticos, estarem se propagando pelo mercado, ainda existem poucos estudos que abordem as propriedades do fruto em si (Tokairin et al., 2018; Taver et al., 2022). Pesquisas acerca do cambuci, não apenas resgatam conhecimento a uma espécie nativa, como também promovem sustentabilidade ambiental e valorização econômica de pequenos produtores e cooperativas locais (Castelucci et al., 2020; Stafussa et al., 2021). Essa integração entre conservação ambiental e desenvolvimento econômico é fundamental para garantir a preservação do cambuci e a valorização de suas propriedades únicas.

Diante desse cenário, o cambuci emerge como um fruto de múltiplas possibilidades. Sua inclusão na alimentação, seja por meio de novos produtos ou como alternativa saudável in natura, apresenta-se como uma solução para a diversificação do consumo alimentar, ao mesmo tempo em que promove a conservação da biodiversidade brasileira (Stafussa et al., 2021; Teixeira et al., 2019). Além disso, o fomento à pesquisa sobre suas propriedades bioativas e aplicações industriais pode contribuir para o desenvolvimento de novas tecnologias e produtos, beneficiando tanto a saúde da população quanto a economia nacional (Soares et al., 2020; Lorençoni et al., 2020). Considerando a riqueza da biodiversidade brasileira e a necessidade de sua preservação, estudar e valorizar o cambuci torna-se uma estratégia que combina ciência, inovação e sustentabilidade.

2 OBJETIVOS

2.1 Objetivo geral

- ✓ Investigar as propriedades físico-químicas, nutricionais, bioativas e antioxidante do cambuci (*Campomanesia phaea*) para promover disseminação e ampliação do conhecimento acerca deste fruto.

2.2 Objetivos específicos

- ✓ Realizar uma revisão de literatura acerca dos aspectos nutricionais e tecnológicos da *Campomanesia phaea;*
- ✓ Caracterizar a composição físico-química e nutricional do cambuci;
- ✓ Investigar os compostos bioativos presentes no fruto;
- ✓ Determinar a atividade antioxidante, utilizando diferentes métodos analíticos e investigar as variações conforme o meio de extração utilizado (etanólico e aquoso);
- ✓ Identificar os compostos voláteis presentes no fruto e correlacioná-los com seus aspectos sensoriais;

Capítulo II

Manuscrito: Composição nutricional e bioativa da Campomanesia Phaea e suas atuais aplicações tecnológicas

Composição nutricional e bioativa da Campomanesia Phaea e suas atuais aplicações tecnológicas

Periódico a ser submetido (1ª submissão):	*Plant Foods for Human Nutrition - 1573-9104*
Maior percentil (Scopus):	*https://www.scopus.com/sources*
Periódico a ser submetido (2ª submissão):	*eFood – 2666-3066*
Maior percentil (Scopus):	*https://www.scopus.com/sources*

ABSTRACT

Cambuci (*Campomanesia phaea*) is a fruit that stands out for its composition as a source of secondary metabolites and for its nutraceutical and functional characteristics. The fruit has a high yield, but is still little consumed, classifying it as an unconventional food plant. His tree is currently at risk of extinction due to widespread deforestation. Cambuci has a high content of ascorbic acid, which favors its antioxidant and anti-inflammatory potential, in addition to being recognized for its role in the immune system and its anti-allergic activity. Carotenoids and polyphenols, specifically flavonoids and proanthocyanidins, are its most prominent bioactive compounds and favor it as a potential benefit to human health. Its phenolic compounds are present in greater amounts than most conventional fruits. Thus, the objective of this article was to gather information about the physical-chemical composition, bioactive activity and its antioxidant properties, as well as to point out its industrial applications.

Keywords: Cambuci; Myrtaceae; Brazilian edible fruits; Unconventional food plants.

1. INTRODUCTION

Cambuci [*Campomanesia phaea* (O. Berg.) *Landrum*] is a little-known fruit, native to the Atlantic Forest, belonging to the Myrtaceae family (Oliveira et al. 2020). This family stands out as dominant in a variety of woody species with financial interest (Silva et al. 2021, Moreira et al. 2022). By growing and developing under adverse environmental conditions, such as drought, floods, strong sunlight, and heat, Myrtaceae fruits represent a rich source of secondary metabolites (Donado-Pestana et al. 2018).

Belonging to the genera Psidium, Myrciaria, Eugenia, and Campomanesia, some other edible fruits of the Myrtaceae family are widely exploited, such as guava (*Psidium guajava*). Other species are more exploited regionally, such as jabuticaba (*Myrciaria cauliflora*) and pitanga (*Eugenia uniflora*), both consumed fresh or transformed into juices and jellies (Tokairin et al. 2018, 2021; Demétrio et al. 2021; Moreira et al. 2022;). Cambuci, the fruit of the family still little explored, needs further studies about its potential.

Campomanesia phaea has a fleshy, juicy, and acidic pulp, with a low amount of seeds and an intense and sweet aroma, allowing its use as an exotic fruit (Tokairin et al. 2018, Moreira et al. 2022). In addition, studies bring the functional characteristics of *C. phaea* fruits, such as their protective effect due to the high presence of bioactive compounds (Tokairin et al. 2018; Castelucci et al. 2020).

Despite this food potential, this species is not included in the consumption and commercialization of people, being classified as a Non-Conventional Food Plant (UFP) (Da Silva Liberato et al. 2019). This underutilization is due to the lack of knowledge about its fruit and the predatory extraction of its wood for the manufacture of tools (Dias et al. 2018). The plant even has the status of a vulnerable species in danger of extinction by the International Union for the Conservation of Nature and Natural Resources (IUCN) (Demétrio et al. 2021; IUCN, 2020).

The expansion of agricultural frontiers and the increase in monocultures (Castelucci et al. 2020), as well as deforestation and illegal logging (Soares et al. 2020), are some of the factors that affect the species. Furthermore, increasing urbanization as opposed to low propagation rate (Demétrio et al. 2021) and mining processes (Moreira et al. 2022) also contribute negatively to the decline in *C. phaea* numbers.

On the other hand, its use as a food source offers an alternative to the food routine that, in addition to encouraging Food and Nutrition Security (FNS), values cultural biodiversity from a nutritional point of view (Jacob, 2020; da Silva et al. 2022). The consumption of native species is still interesting for the market (Otero, 2019) for promoting positive economic impacts for local populations and strengthening sustainability (Soares et al. 2019).

Thus, given the nutritional, bioactive and technological potential of *C. phaea*, this review focused on its physical chemical composition, bioactive activity, antioxidant properties and possible technological applications.

2. DATA SOURCES AND SEARCH STRATEGY

Five databases were used to produce this review (Scopus, ScienceDirect, SpringerLink, Medline/Pubmed, and Web of Science) and an online library (SciELO), as seen in Figure 1.

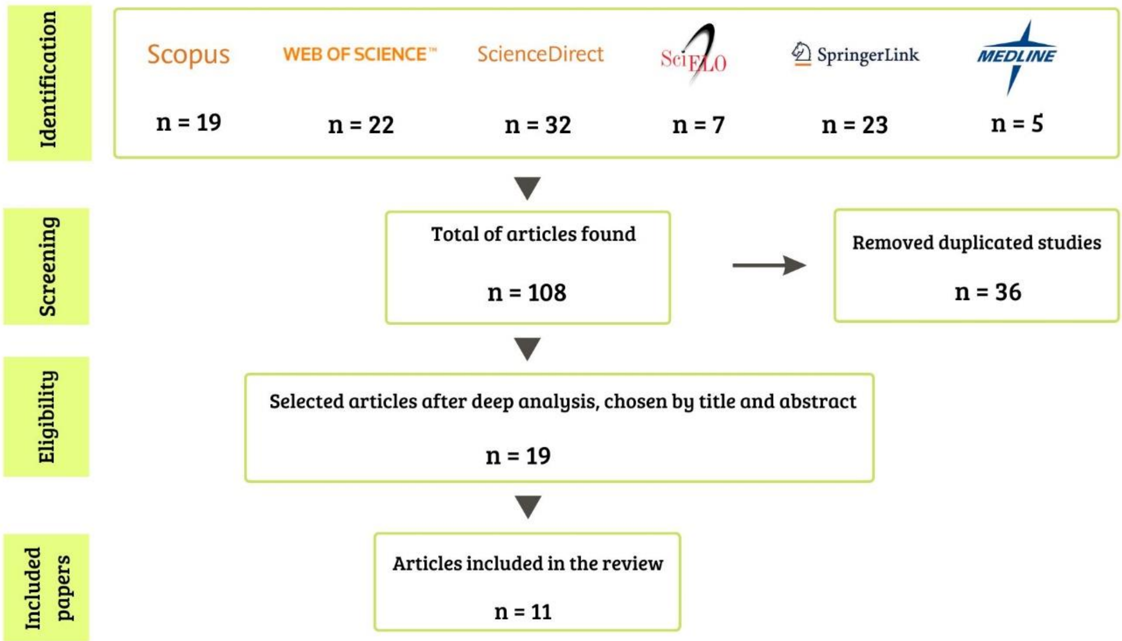

Figure 1: PRISMA flowchart of the review study screening process.

Search inclusion criteria were studies that contained the term '*Campomanesia phaea*' and had been published from 2018 to 2024. These articles contained information about bioactive compounds, physicochemical characteristics, and antioxidant activity. Duplicated articles and publications outside the scope of this search were removed according to the exclusion criteria.

3. RESULTS AND DISCUSSION

A total of 108 articles were found published in the databases and in the online library in the period established for this research. The database that stood out for the number of publications of articles related to *Campomanesia phaea* was Science Direct, with a total of 32 articles, 17 of which were original research articles. Despite the large number of publications found in this database, compared to other databases, many of them were not related to the scope of this review in question. 21 of these Science Direct articles addressed cambuci in the agricultural sciences or because of its genetic issues.

In 2018, the Science Direct database had six publications related to *C.phaea*, followed by Scopus and Scielo with three. Springerlink and Web of Science followed with two publications and only Pubmed/Medline did not mention publications on the subject in 2018. The highlight remains ScienceDirect in 2019 with six publications, followed by Springerlink with four. While for Scopus, Web of Science and Medline, only one article was found.

In 2020, we can see in the graphical representation (Figure 2) an increase in the number of publications, with 9 more articles than in 2019. Scopus, Web of Science and Medline are tied in number of scientific publications, with five articles each. In addition, Medline/Pubmed reached its publication peak with five articles published. While Springerlink and ScienceDirect had a drop in the line of publications, presenting only three studies. Compared to the previous year, Scielo publications increased in 2020, with an article on the subject.

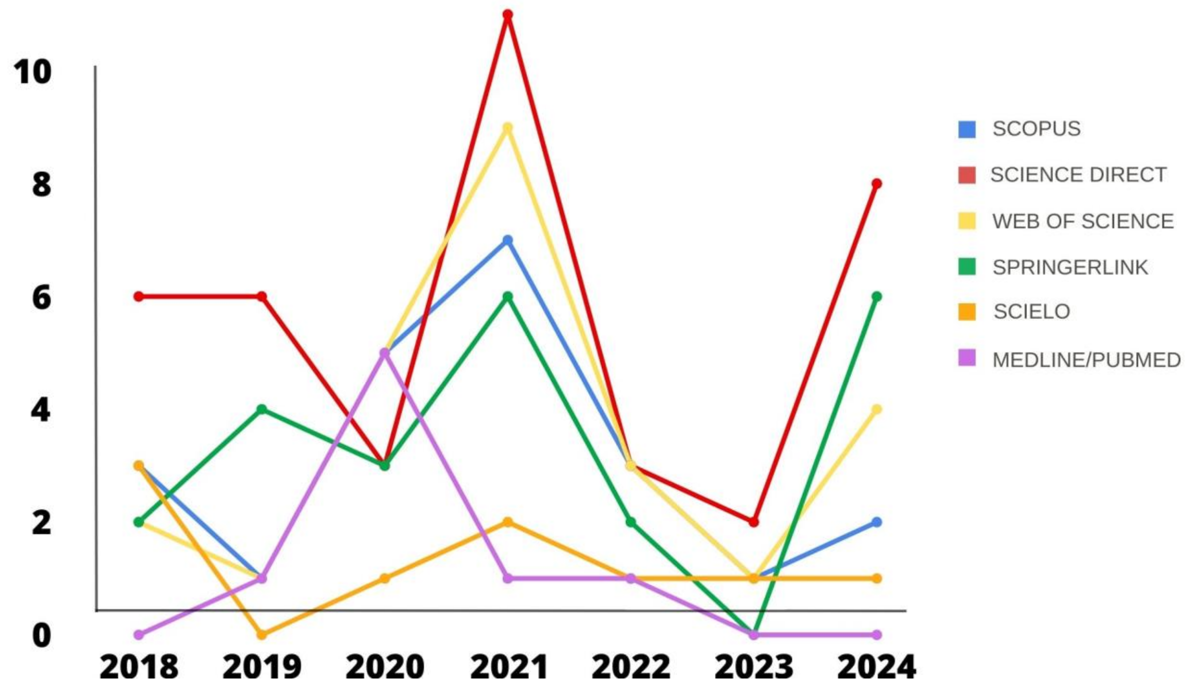

Figure 2: Articles found using the term "*Campomanesia phaea*" in the databases from January 2018 to September 2024.

There was a significant increase in publications in 2021, increasing to 14 more studies compared to the previous year. We can highlight Science Direct with eleven articles, obtaining its highest peak of studies about cambuci. This considerable increase in studies in 2021 can be explained by a series of events promoted by the Auá Institute, due to a record harvest of the fruit this year (Auá Institute, 2021).

When analyzing the number of articles published in 2022, we observed a decrease of 23 studies. And in the following year, the publication of these articles continued to decrease in most databases, with SpringerLink and Medline/Pubmed not publishing any articles on *Campomanesia*.

From 2023 to the present, however, we have observed a new increase in the publication of these articles in most databases. This perspective can be justified by a growing interest in functional foods and natural ingredients by society. This interest may have led to a reevaluation of the properties of cambuci, motivating new research. Researchers Moreno et al. (2024), for example, justify their study of cambuci due to the industrial interest in the use of compounds present in the fruit, such as ellagic acid, used to synthesize bioengineering materials.

These data highlight the importance of articles that gather information about cambuci. This fruit is still little explored and requires studies that encourage and disseminate its knowledge and, consequently, its consumption and commercialization.

3.1 Characteristics

The plant belongs to the Myrtaceae family, which has great ecological importance, with about 121 genera and 5,800 tree species (De Paulo Farias et al. 2020). Like most fruits in this family, cambuci grows under varied environmental conditions such as drought, flood, sun, and heat (Donado-Pestana et al. 2018).

The cambucizeiro tree (Fig. 2a), where cambuci comes from, is native to Brazil and comes from the Atlantic Forest (Silva et al. 2021). It has a height of three to sixteen meters and a trunk diameter of 20 to 30 cm (Donado-Pestana et al. 2018; Santoro et al. 2020). The tree has a slow development and its trunk is smooth and peeling, with excellent quality wood (Instituto Auá, 2021, Prado et al. 2022). Its leaves (Fig. 2b) are small with veins in arcs and are shiny throughout the year (Oliveira et al. 2022). Its flowering is white and showy from August to November (Silva et al. 2018). It has pedunculated axillary flowers, solitary or gathered in inflorescences with floral buds with calyx (Oliveira et al. 2022). Its seasonality period is short, with abundant fruiting between the months of February and April (Paes et al. 2019).

Cambuci production is on the rise, data brought by Prado et al. (2022) show that the 2021 crop increased by 20% compared to 2020. Its consumption, however, is still reserved for the interior of São Paulo, a place of its most effective production (Paes et al. 2019; Tokairin et al. 2023). Precise data were not found in the literature regarding the average production of cambucis per tree, precisely because the fruit is still quite regionalized. It is known, however, with data from 2014, provided by the AHPCE (Association Holistic of Production Community Ecological) that the production of the fruit reached a harvest of 400 tons, accounted for by its producers.

C. phaea had its scientific name first described by Berg in 1857 as *Abbevillea phaea*. Its popular name cambuci is of indigenous origin (Tupi-Guarani) and means ‘pot of water’. This name was given due to its ovoid-rhomboid shape with a horizontal line that divides it into two symmetrical parts, resembling a ceramic vase (Instituto Auá, 2021; Silva et al. 2021). Silva et al. (2021), this is a specific format only observed in cambuci fruits.

The fruit (Fig. 2c) has a diameter of 49mm, reaching 55mm, and an average length of 35 to 37mm (Table 1). It has few seeds and, even when mature, is green or green with yellow tones (Oliveira et al. 2020). In a native environment, it serves as food for birds, monkeys, and dolmens, and its dispersion is linked to this group of frugivorous vertebrates (Instituto Auá, 2021).

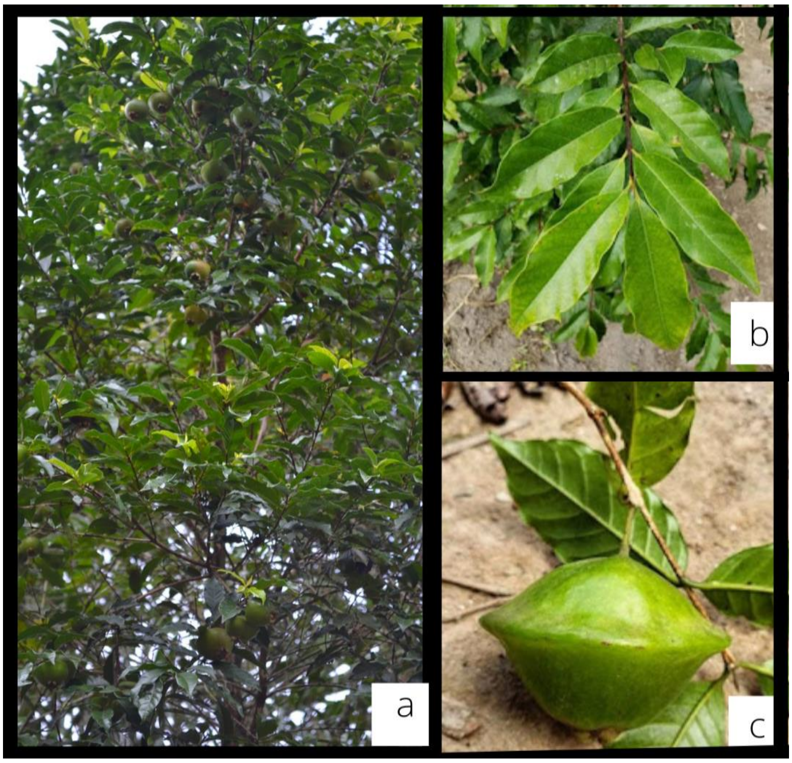

Figure 3: *Campomanesia phaea* tree (a); leaves (b) and ripe fruit (c); Authors: Adhemar Gomes - Pictures of accessions were obtained from Blog Frutas Raras (2022).

C. phaea has attractive sensory characteristics and is recognized for delighting the sense of smell with its intense, pleasant, and sweet-citrus aroma (Paes et al. 2019). It has a thin rind whose flavor resembles a mixture of lemon (*Citrus limon*) and jabuticaba (*Plinia cauliflora*), while its watery and juicy pulp comprises acidity as the predominant element, being also characterized by its astringent and sour flavor (Dias et al. 2018; Tokairin et al. 2018; Wczassek et al. 2019). These appealing sensory characteristics make it a more remarkable food (Tokairin et al. 2018; Rojas et al. 2021).

Literature data show that the fresh weight of cambuci can vary from 39.51g to 42.03g (Table 1). Tokairin et al. (2023), brought in their study, the fruit at different stages of maturation and analyzed the weight loss and firmness of the pulp. Regarding weight loss, they observed that it was not influenced by ripening, as the fruits harvested in different maturation processes had similar losses. Regarding firmness, they concluded that the fruit softens with time. This data is important, since *C. phaea* is harvested by producers only when the fruit easily detaches from the tree or when it falls to the ground, which can result in loss of fruit quality or urgency in conservation (Dellaqua et al. 2022).

Table 1 - Physical characterization of cambuci fruit

Component	Content	Units	Reference
Fresh weight	39.51 - 42.03	g	Tokairin et al. (2018), Dias et al. (2018)
AL	35.10 - 37.12	mm	Tokairin et al. (2018), Dias et al. (2018)
AD	49.05 - 55.00	mm	Tokairin et al. (2018), Dias et al. (2018), Donado-Pestana et al. (2018)
Yield	89.34	%	Tokairin et al. (2018)
Firmness	1 - 7.69	N	Tokairin et al. (2023), Dias et al. (2018)
Peel	10.66	%	Tokairin et al. (2018)
Colour			
L	57.97		Dias et al. (2018)
a	- 3.93		
b	10.46		
h	102	ºhue	Tokairin et al. (2023)
C	18		

*AL = average length; AD = average diameter;

Yield and bark percentage, were characterized only by Tokairin et al. (2018) and correspond to 89.34% and 10.66%, respectively. Other authors report the high yield of the fruit, such as Teixeira et al. (2019), but do not provide quantitative data. Likewise, Dias et al. (2018) complement highlighting the pulp dilution, due to the strong flavor that further favors the fruit yield.

Regarding the length (AL) and diameter (AD) of the fruit, the variation was not very large, varying more in diameter 49.05 - 55.00 mm than in length 35.10 - 37.12 mm. According to the characterization study of cambuci in different accessions carried out by Dias et al. (2018), this variation is normal, both in fruit shape and size.

Cambuci colour varied with a (-3.93) tending to yellow and b (10.46) showing the expressiveness of green (Table 1), characteristic colour of the fruit. The parameter L(luminosity) demonstrated the intensity of the fruit colour (57.97) (Dias et al. 2018). The hue angle (h) and chroma (C) indicate the hue of the fruit. Tokairin et al. (2023) when comparing cambucis at different maturation times, observed that variations in color angles occur, but in the fruit skin they manifest themselves in a very modest way, difficult to be noticed. These parameters must be taken into account to generate information, both for the agro-industrial sector and for acceptance by the market as a whole.

Some of these data may vary due to oscillation in soils, harvest period or due to maturation stage (Tokairin et al. 2023). Dias et al. (2018) bring that the planting of cambuci occurs in mountainous regions, as well as in regions close to the sea. They observed that fruits harvested in different accessions, without specifying the soil of each accession, had different morphological characteristics, such as firmness. It would also be interesting, studies that brought variations in the composition of the fruit in different years, but no study was found with this information.

3.2 Chemical and Nutritional Composition

Knowledge about the nutritional and chemical properties of *C. phaea* is essential to characterize it. Its attributes will determine essential quality aspects for its use and later for the elaboration of industrialized products (Neto et al. 2018). Information on moisture, pH, titratable acidity, content of soluble solids, asher, total fiber, soluble fiber, insoluble fiber, proteins, lipids and carbohydrates of cambuci fruit were gathered in Table 2.

Table 2 - Chemical and Nutritional Characterization of Cambuci

Component	Content	Units	Reference
Moisture	84.41 – 89.00	%	Donado-Pestana et al. (2018), Moreno et al. (2024)
pH	2.4 – 3.0		Tokairin et al. (2018), Dias et al. (2018), Donado-Pestana et al. (2018)
TA	1.06 - 2,5	%	Tokairin et al. (2018), Dias et al. (2018), Tokairin et al. (2023)
SSC	1.70 - 10,40	ºBrix	Tokairin et al. (2018), Dias et al. (2018), Tokairin et al. (2023)
Ashes	2.20 – 2.64	%	Moreno et al. (2024)
Total fiber	4.00	%	Donado-Pestana et al. (2018)
Soluble fiber	5.50 – 6.51	%	Moreno et al. (2024)
Insoluble fiber	30.68 – 33.12	%	Moreno et al. (2024)
Proteins	1.17 - 8,86	%	Moreno et al. (2024)
Lipids	1.44 - 4,60	%	Moreno et al. (2024)
Carbohydrates	8.44 - 11,62	%	Moreno et al. (2024)

*AL = average length; AD = average diameter; SSC = soluble solids content; TA = titratable acidity~~;~~

Cambuci pulp is identified by low pH values (2.54 - 2.88). Dias et al. (2018) and Paes et al. (2019) address in their studies the acidic pH as a limiting factor for the fresh consumption of the fruit, comparing it with a lemon. In a study by Neto et al. (2018) with the Galician lemon (*Citrus aurantifolia Swingle*) at different stages of maturation, they obtained pH values with an average of 2.69. Low pH values can, however, be interesting in the manufacture of industrial products. Acidity, in addition to hindering the development of microorganisms, avoids the need for a lot of thermal processing (Neto et al. 2018).

Likewise, the titratable acidity of cambuci was low, ranging from 1.06% - 2,5%. Tokairin et al. (2018) in their study compared cambuci as a variant between the sour passion fruit flavor (2.78%) and 'Pera' orange (0.95%).

Regarding the soluble solids content, the authors obtained values between 1.7 and 10.40°Brix. These values were close to those found by Ferreira et al. (2018), who obtained an average of 7.67°Brix in different lemon genotypes. This analysis is widely used to determine the soluble compounds present in the fruit and also to identify the concentration of sugars present there. As expected, cambuci can present very different levels of sweetness, depending on its accession, the climatic conditions in which it was planted, and the stage of ripeness it is in (Dias et al. 2018; Donado-Pestana et al. 2018; Oliveira et al. 2020).

Regarding fiber content, Santoro et al. (2022) draws attention to the fact that this is a functional compound present in the fruit. Moreno et al. (2024) show that the high content of insoluble fiber in cambuci (30.68% to 33.12%) is quite significant and suggests that the consumption of this fruit may be especially beneficial for intestinal health, preventing problems such as constipation. Furthermore, the combination of soluble and insoluble fibers makes cambuci a balanced fruit in terms of benefits for digestive and metabolic health.

Fruits are not traditionally sources of protein. Cambuci presented protein content ranging from 1.17 to 8.86%. Dias et al. (2018) in their study characterizing cambucis, highlighted the pectin in the fruit. Although they did not provide the amount found in the fruit, they drew attention to the gelling power that this polysaccharide has and how interesting this can be for processes in the food industry. Cambuci also did not appear to be a source of lipids. The variation in these levels can be explained both by the planting soil and by genetic conditions, since the main mode of reproduction of the fruit is sexual, by seed dissemination (Tokairin et al., 2018).

The carbohydrate content of cambuci varied between 8.44% and 11.62%, representing a moderate amount for a fruit. The analysis of the sugar profile, carried out by Tokairin et al. (2023) revealed that glucose is not the main sugar present in these fruits, with its highest concentration observed in greener fruits, while more ripe fruits have a lower expression of this sugar. This characteristic may indicate a conversion of glucose into other sugars, such as fructose and sucrose, as the fruit ripens, which influences the sweetness profile and glycemic impact of the fruit. This variation in the sugar profile may make cambuci an interesting option both for fresh consumption and for the development of food products, with possibilities for adaptation depending on the stage of ripeness and consumer preferences.

3.3 Bioactive Compounds

Bioactive compounds are influenced by several factors intrinsic and extrinsic to the leaves, each region and each cultivar will present different peculiarities (Lorini et al. 2021) and therefore the need for this study. These chemical compounds have several antioxidant properties that act on oxidative stress, in the pathogenesis of cardiovascular, antiviral, hormonal, and anti-inflammatory diseases (Lôbo et al. 2020). Table 3 shows the bioactive compounds found in the literature about cambuci.

Table 3 - Bioactive compounds quantified in cambuci.

Class	Content	Units	Fraction	Reference
Polyphenols	6.82	mg GAE/mL	Fruit	Donado-Pestana et al. (2021)
Ellagic Acid	240	mg/100g	Fruit	Moreno et al. (2024)
Phenolic	139 - 695.55	mg 100 g^{-1} GAE	Fruit	Dias et al. (2018), Taver et al. (2022), Tokairin et al. (2018, 2023)
	3.43	mg GAE mL-1	Pulp	Castelucci et al. (2020)
	5189.09	mg GAE/100 g dw	Fruit puree extracts	Stafussa et al. (2021)
	0,49 - 1,10	µg CE/mL	Juice	De Carvalho et al. (2021)
Flavonoids	1.40	mg of quercetin 100 g^{-1}	Pulp of fruit	Castelucci et al. (2020)
Total Tannins	>50	mg 100g^{-1}	Fruit	Tokairin et al. (2023)
Soluble Tannins	58	mg 100g^{-1}	Fruit	Tokairin et al. (2023)
Proanthocyanidins	0.38 20.6	mg Cya-chlor/mL mg 100 g $^{-1}$	Fruit Fruit	Donado-Pestana et al. (2021) Taver et al. (2022)

Carotenoids	2.99	µg of β-carotene g-1	Pulp of fruit	Castelucci et al. (2020)

GAE = gallic acid equivalents; Cya-chlor = Cyanidin-3-O-rutinoside chloride; CE = catechins equivalents.

Polyphenols are bioactive organic compounds present in fruits and vegetables. They play a primordial metabolic, in defense against microorganisms and predators, protection against ultraviolet radiation and oxidative stress, and as signaling compounds to attract pollinators (Rodrigues et al. 2021). Donado-Pestana et al. (2021) when evaluating the curative effect of cambuci polyphenols (Table 3), showed that they improved insulin resistance in the liver and muscle tissues and hepatic steatosis.

Tokairin et al. (2018) showed 617.90 mg GAE g^{-1} of total phenolic components in their study and classified the fruit as a possible source of this metabolite. This value is comparable to that found by Neri-Numa et al. (2018) in their study with açaí (*Euterpes oleracea*), with 424.9 mg GAE g^{-1}, and with buriti (*Mauritia flexuosa*), with 435.08 mg GAE g^{-1}, both considered sources of phenolic compounds.

Variations found in the studies of total phenolics are mostly due to the part of the fruit in which the analysis was performed. Pulp and juice are parts mixed with water and therefore have lower values of phenolic components. The fruit puree extract, on the other hand, has its components concentrated and tends to have higher values. Moving away from the average values of this compound, find the study by Taver et al. (2022), but the authors noticed this difference when comparing their values with those of other studies. They report that this difference may have occurred due to genetic variations, geographic location and environmental factors (periods of rain, drought, incidence of light), in addition to harvesting in different seasons of the year.

Despite the lower values found by the authors, cambuci still has higher concentrations of phenolic components than conventional fruits. Taver et al. (2022) brought this comparison with watermelon (55.66 mg 100 gÿ1 of GAE), pineapple (69.76 mg 100 gÿ1 of GAE), passion fruit (61.0 mg 100 g of GAE), mango (60.0 mg 100 gÿ1 of GAE), and melon (69.98 mg 100 gÿ1 of GAE), indicating that *C. phaea* is a source of phenolic compounds.

Some authors are already studying the probable therapeutic benefits of cambuci in health. Wczassek et al. carried out the pharmacological evaluation of the bioactive compounds present in the hydroalcoholic extracts of the fruit in a study with rats. They report a performance in the central nervous system, represented by the grooming and cardiovascular activities of hypotension and bradycardia.

Flavonoids belong to the group of phenolic compounds and were identified separately by Castelucci et al. (2020) who found 1.40 mg of quercetin 100 g-1. In their study, the authors identified 11.78% of bioaccessible fractions of the total phenolic content of cambuci after simulated gastric and intestinal digestion. This value indicates that there was a considerable decrease in the total phenolic content after the gastric and intestinal digestion process.

Tannins are natural compounds, produced by various fruits and plants, which denote high antioxidant potential due to their high degree of hydroxylation, molecular weight and aromatic rings (Tokairin et al. 2023). They are divided into hydrolyzable, condensed and complex. Tokairin et al. (2023) showed the decrease that occurred in cambucis as the ripening stage increased. This decrease is satisfactory, as it triggers a reduction in astringency, a desirable factor for later consumption of the fruit. Regarding the values of tannins in cambuci shown in Table 3, we brought the fruit already at the stage in which it is commonly consumed.

The authors Donado-Pestana et al. (2018) report in their review of fruits of the Myrtaceae family that the main classes of polyphenols found in cambuci are tannins. From this class, the authors also highlighted ellagitannins and proanthocyanidins as more evident in the fruit.

Donado-Pestana et al. (2021) presented 0.38 mg Cya-chlor/mL^2 of proanthocyanidins and highlighted this value as high. Probably due to differences in methodology, Taver et al. (2022) ended up finding even higher values (20.6 mg 100 g^{-1}) Proanthocyanidins are a specific class of polyphenols found in some plants and foods, which serve as a natural defense, but are also useful for humans. Taver et al. (2022) point out that despite being responsible for the high astringency and acidic taste of cambuci, proanthocyanidins have high antioxidant activity and potential health protective effects. Petrolini et al. (2021) also points out these molecules as executors of the reduction of reactive oxygen species, an important factor when these species are in imbalance in the body.

Carotenoids are fat-soluble chemicals responsible for the yellow, orange, and red pigmentation of plants, fruits, vegetables, and microorganisms. They play a substantial role in photosynthesis due to their photoprotective properties. In addition, they are recognised in nutrition for acting as regulatory and antioxidant substances (Rodrigues et al. 2021). Carotenoids also contribute to its therapeutic effects, acting as anti-inflammatory, antidiabetic, anticancer, neuroprotective and immunomodulatory (Nabi et al. 2020).

The only study that evaluated the total composition of carotenoids in cambuci were Castelucci et al. (2020). According to them, despite having carotenoids in its bioactive composition (Table 3), cambuci does not have a relevant value, which would be above 20 µg g^{-1}. This value may not express the value of the fruit itself, as it used pulp in its analysis. The authors diluted the fruit with water in a ratio of two parts of the fruit to one of water (2:1). Biazotto et al. (2019), in a study carried out with the edible parts of another variation of Campomanesia (*Campomanesia coubaril*), found a variation in total carotenoid content of

43.87 - 83.23 μg/100g. These values indicate that the species *C. phaea* may also have a good potential regarding its carotenoids.

To present the bioactive compounds of native fruits such as cambuci can contribute to the population's increased consumption. Pharmaceutical and food companies seek this information to launch products with preventive and therapeutic bases against chronic diseases related to oxidative stress (Donado-Pestana et al. 2021).

3.4 Antioxidant property

An antioxidant substance can be defined as a chemical substance that inhibits or slows down the oxidation process (Stafussa et al. 2021). From a biological point of view, antioxidant activity acts against the harmful effects of reactions that promote the oxidation of macromolecules or cellular structures (Verruck et al. 2018).

The consumption of antioxidants, mainly present in fruits and vegetables, is associated with a lower incidence of diseases related to oxidative stress (Verruck et al. 2018; Stafussa et al. 2021). Recently, natural antioxidants from fruits have been correlated with the inhibition of α-amylase and α-glucosidase enzymes responsible for helping to decrease postprandial hyperglycemia (Sun et al. 2020).

The Myrtaceae family is recognized for its functional fruits, with antioxidant, antimicrobial and/or anti-inflammatory properties (Teixeira et al. 2019). Wczassek et al. (2019) attributed the antioxidant properties of cambuci to its bioactive compounds, such as L-ascorbic acid and its phenolic compounds.

It is believed that the antioxidant capacity of the fruits correlates with the colour presented (Cömert et al. 2020) and can be measured through different methods, where each one of them acts through different mechanisms of action and interacts in different ways with the samples. In this way, evaluating the antioxidant activity by different methods becomes interesting to seek the result that best reflects the reality (Otero et al. 2020). In table 4, several analyzes (ORAC, NADH, DHR, DAF-2, ORAC, DPPH, βcarotene, ABTS and ascorbic acid analysis) were performed to verify the antioxidant activity of cambuci in different fractions of the fruit (fruit, pulp, juice, and puree extract).

Table 4 - Antioxidant activity of cambuci.

Analyses	Content	Units	Fraction	Reference
DPPH	65.03	µmol g^{-1} Trolox	Fruit	Tokairin et al. (2018)
DPPH	93.13	% of sequestration	Fruit	Dias et al. (2018)
DPPH	61.86	µg trolox g^{-1}	Pulp	Castelucci et al. (2020)
DPPH	229.56	µmol TE/g dw	Fruit puree extract	Stafussa et al. (2021)
ABTS	32.06	µmol trolox g^{-1}	Pulp of fruit	Castelucci et al. (2020)
ABTS	371.60	µmol TE/g dw	Fruit puree extracts	Stafussa et al. (2021)
ABTS	10,5	µmol trolox g^{-1}	Fruit	Taver et al. (2022)
Bcarotene	90,62	% of protection	Fruit	Dias et al. (2018)
NADH\PMS	575.36	µg mL^{-1}		
DHR	74.14	µg mL^{-1}	Fruit	Soares et al. (2020)
DAF-2	16.96	µg mL^{-1}		
HOCL	53,9	µg mL^{-1}		Taver et al. (2022)
ORAC	0.98	mmol.TE.100 mL^{-1}	Frozen pulp (Juice)	de Carvalho et al. (2021)
ORAC	9,17	µmol TE por g^{-1}	Fruit	Taver et al. (2022)
ORAC	68,94	µmol TE por g^{-1}	Fruit	Soares et al. (2020)
Ac. Ascorbic	72.16 - <150	mg.100g^{-1}		Dias et al. (2018), Tokairin et al. (2018), Taver et al. (2022), Tokairin et al. (2023)

DPPH = 2-diphenyl-1-picrylhydrazyl radical scavenging activity; ABTS = 2,2-azino-bis(3-ethylbenzothiazoline-6- sulphonic acid); ORAC = oxygen radical absorbance capacity; PMS = phenazine methosulfate; DHR = diidrorodamina 123; DAF-2 = diaminofluoresceína-2;

Tokairin et al. (2018) analyzed the antioxidant activity (AA) of cambuci for its ability to scavenge the free radical DPPH and obtained an average of 65.03 μmol of Trolox g^{-1} in the fresh mass. Da Silva et al. (2022) analyzed the AA of uvaia (*Eugenia uvalha*), also belonging to the Myrtaceae family. The uvaia analysis was done by the DPPH method and they obtained a range of 9.94 – 29.71 μmol of Trolox g^{-1} and classified it as a fruit with high antioxidant activity in vitro.

Using the ABTS free radical scavenging method, AA from cambuci pulp, brought by Castelucci et al. (2020) showed 32.06 μmol Trolox g^{-1}. Even the authors using cambuci in the form of pulp (2 parts of fruit to 1 part of water), they obtained values considered high. Silva et al. (2022) also analyzed uvaia using the ABTS method and obtained the range from 33 to 923.5 μmol Trolox g-1 (f.w.).

Dias et al. (2018) when analyzing AA by βcarotene, obtained 90.62% protection. According to the authors, an antioxidant potential above 70% is considered ideal for the inhibition of lipid oxidation.

There are several mechanisms of AA and to verify if the fruit has high or low activity, research by more than one method is necessary (Castelucci et al. 2020). There was a great variability of methods used in the analysis of the antioxidant activity of cambuci, which made the discussion difficult, as they do not corroborate each other. Rodrigues et al. (2021), reported in their study another difficulty in relation to the methods of analysis as they are not able to accurately produce the antioxidant effect of the compounds in the fruits, in addition to their non-specificity.

Despite the difficulties, some authors such as Soares et al. (2020), who performed the ORAC deactivation analysis, compared their results for *C. phaea* with fruits such as mango (54.75 μmol TE per g) and watermelon (17.97 μmol TE per g). They certified that cambuci showed higher antioxidant activity (68.94 μmol TE per g). Likewise, despite having exposed an analysis carried out with cambuci juice, de Carvalho et al. (2021) bring in their discussion that *C. phaea* has good antioxidant capacity (0.98 mmol.TE.100 mL^{-1}).

The analysis of ascorbic acid in cambuci brought favorable values for it to be included in the diet as a source of vitamin C. According to Tokairin et al. (2018) a cambuci fruit with an average weight of 42.03g can provide 50.55% of the daily requirement of ascorbic acid, which according to the RDA (Recommended Daily Allowance) is 100-120mg/day^{-1}. This acid is recognised for its antioxidant effect and in orchestrating the immune system, but in addition, it also has anti-allergic and anti-inflammatory activity (Jafari et al. 2019).

Thus, by the methods used for analysis, we realized that cambuci has potential to be used by delaying oxidative degradation reactions, which can have a positive impact on human health. Also because it belongs to the Myrtaceae family, it has been drawing the attention of the industry in the area of functional food development due to the potential added by its antioxidant and anti-inflammatory capacity (Teixeira et al. 2019). However, more studies with in vivo and in vitro methods (using cells) are needed to more effectively evaluate the antioxidant effect, in addition to evaluating which compounds actively contribute to it.

3.5 Applications Current or Industrial

Recognizing physicochemical aspects favor the search for better ways to take advantage of the species' potential (Teixeira et al. 2019). The consumer market becomes increasingly attentive to products that can promote potential health benefits. Thus, interest in studying the possible functional capabilities of bioactive compounds applied to food has grown (Donado-Pestana et al. 2018).

Cambuci has a wide range of potential applications in the food field, as well as in microbiology, pharmaceuticals, cosmetics, and natural medicine (de Carvalho et al. 2021). The possibility of health benefits from its bioactive components and the sensory characteristics present are some of the factors that favor the interest in the consumption of *C. phae* fruits and encourage the use of processing technologies for its commercialization (Tokarin et al. 2018, 2023).

Although consumers have a greater predilection for fresh fruits due to the attraction of physical characteristics (Tokarin et al. 2018), in the case of cambuci, fresh consumption is not encouraged due to the high acidity and astringency present in this fruit (Dias et al. 2018). Paes et al. (2019), show that it is possible to reduce this acidity through dehydration by osmosis, favoring the improvement of organoleptic and nutritional characteristics.

Technological applications involving cambuci, observed in Figure 3, show that it is possible to use the fruit in the production of juices, jams and jellies (Tokarin et al. 2018), pate, pickles, fruit paste, tea, chili sauce, flour (Ronchi, 2021), ice cream and alcoholic beverages (Donado-Pestana et al. 2018; Wczassek et al. 2019).

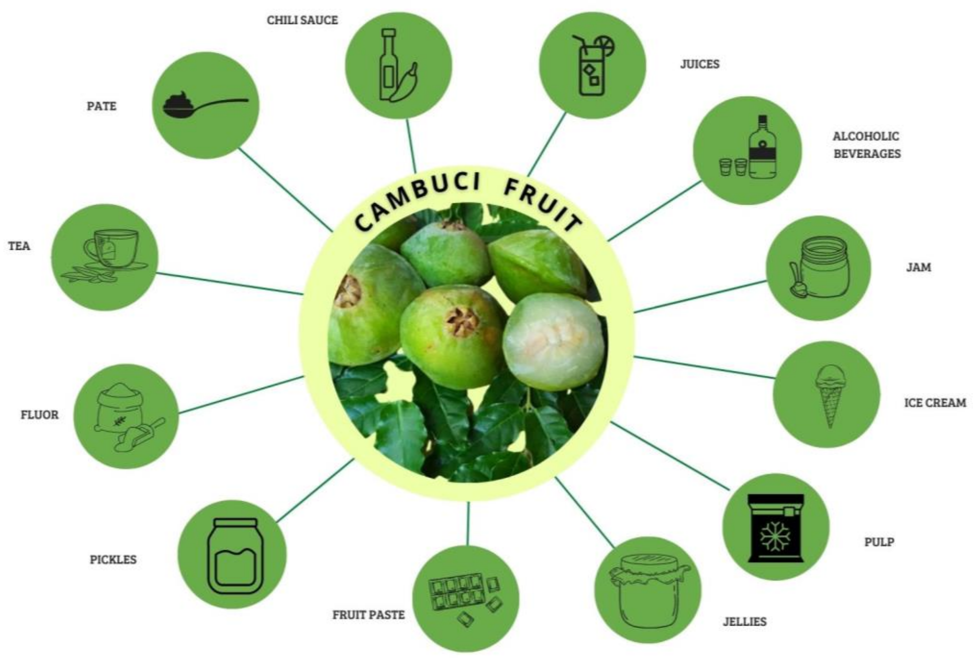

Figure 4 - Products using cambuci found in the literature.

A study developed by Dias et al. (2018) showed the feasibility of processing *C. phae* fruits in the production of jellies based on the influence of physicochemical characteristics, bioactive compounds, and rheological properties. In order to discover which fruits had the greatest potential for industrial use, the author performed a sensory analysis using the acceptance test to assess the attributes of color, texture, flavor and overall impression, on a 9-point structured hedonic scale. The result indicated that the consumer's preference is greater for more accentuated green jellies and softer textures.

Despite the lack of knowledge, the commercialization of cambuci has expanded in local communities through the development of artisanal products. The application of *C. phae* as a raw material in food matrices for human consumption can positively impact producers' financial sector (Teixeira et al. 2019). It also favors the socio-environmental aspect by valuing a Brazilian native species at risk of extinction (Demétrio et al. 2021). Furthermore, its use can encourage the consumption of organic foods (Ronchi, 2021) and consequently generate greater dissemination of information about the fruit.

Consumers have a greater demand for products with information related to health benefits (Donado-Pestana et al. 2018). Thus, given the functional properties of cambuci, the possibilities for new products are vast, including energy and nutritious drinks, yogurt syrups, gelatin gels, mousses, flour for cookies or bread, and fillings for sweet preparations such as cakes. However, further confirmatory studies are still needed on the bioactive compounds and chemical aspects present in native species and their benefits. As Teixeira et al. (2018) pointed out, this gap in scientific evidence makes it difficult to expand the development of new food products using them.

This interest in developing scientific research on cambuci can positively impact the academic area and human health from the perspective of nutritional composition. Moreover, it is a possibility to value native plants endemic to deprived areas with income generation (Soares et al. 2019), as well as the environmental preservation of an endangered species (IUCN, 2020).

4. CONCLUSION

This review brought a compilation of data found in the scientific literature that show the potential of *C. phaea* in human food. The presence of phenolic compounds and their bioactive and nutritional potential show that their use in routine food should be valued.

Cambuci proved to be an important source of ascorbic acid, which can be an ally to strengthen the immune system. More studies are still needed to provide information about other nutrients that may be present in *C. phaea*. There is also evidence of cambuci as a fruit with high levels of phenolic compounds, which can then fight degenerative processes by increasing cellular resistance. However, more detailed research is still needed.

By gathering information about the antioxidant properties of cambuci, we could see that it has a high antioxidant capacity. This high capacity can be interesting to meet the demand of the population that is increasingly concerned about health. In this way, food industries can in the future use cambuci to enrich food formulations.

In addition, cambuci is also a fruit with great technological potential and with few studies exploring this theme. It is necessary to explore its high percentage of yield and its striking flavor, to manufacture products that combine its positive sensory aspects with its nutritional and bioactive potential.

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Capítulo III

Manuscrito: Cambuci (Campomanesia Phaea)- Myrtacea: Um estudo abrangente de sua composição nutricional e bioativa

Cambuci *(Campomanesia Phaea)*- Myrtacea: A Comprehensive Study of its Nutritional and Bioactive Composition

Periódico a ser submetido (1ª submissão):	*Food Chemistry - 1873-7072*
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ABSTRACT

Cambuci (*Campomanesia phaea*) is a fruit native to the Atlantic Forest, belonging to the Myrtaceae family, which currently comprises a group of unconventional food plants (UFPs). Its pulp has an essentially sweet odor. Its flavor, however, is sour, reminiscent of lemon. This study aims to evaluate the nutritional properties, bioactivity, antioxidant and volatile composition of cambuci. The fruit has a high yield (91.8 - 92.4%), high moisture (86.04%), and acidic pH (2.96). It presented considerable data for bioactive compounds such as phenolic (545.3 $mg.g^{-1}$ GAE), carotenoids (9.17mg of β-carotene.g^{-1}), and chlorophyll (41.79 $mg.g^{-1}$) compounds. The antioxidant activity, evaluated by the ABTS (326.25 mmol Trolox.g^{-1} in ethanol and 275.15 mmol Trolox.g^{-1} in water) and FRAP (162.4 µmol $Fe^{+}.g^{-1}$ in ethanol and 251 µmol $Fe^{+}.g^{-1}$ in water) methods, demonstrates high antioxidant efficacy. As for volatile composition, fresh/citrus, pine/cedar, and citrus compound aromas were identified, mainly from the class of terpenes recognized for their aromatic and medicinal properties, and new compounds were identified for the first time in cambuci. In conclusion, this study highlights the ability to include this fruit in the dietary routine as a food with functional potential. It highlights physical-chemical qualities that can favor its use by the food industry.

Keywords: Cambuci; Myrtaceae; Brazilian edible fruits; Unconventional food plants.

1. INTRODUCTION

The cambuci [*Campomanesia phaea (O. Berg.) Landrum*] is a fruit from the cambuci tree, a small to medium-sized tree native to the Atlantic Forest biome (Santoro et al., 2022). It belongs to the Myrtaceae family and is known for its medicinal properties and floristic diversity (Cruz et al., 2023). This plant was once at risk of extinction and is currently classified among the Unconventional Food Plants (UFP) (IUCN, 2020; Teixeira et al., 2019).

This fruit is distinguished by its ovoid-rhomboid shape with a horizontal crest and is green to yellow-green in color when ripe (Oliveira et al., 2020). Its odor is sweet, but its flavor is sour, similar to lemon (*Citrus limon*) (Silva et al., 2021). This similarity with lemon and the recognition of the Myrtaceae family highlights the need for detailed investigation of the nutritional properties of this fruit and its potential applications.

Cambuci production occurs, on average, after five years of planting with seeds, and can produce up to 200 kilos per harvest (Agrolink, 2024). Previously, its consumption was limited to indigenous people, quilombolas, local communities, small farmers, rural residents and local traders (Lamarka et al., 2024). However, for some years now, there has been an annual festival known as Rota do Cambuci, which has played a crucial role in promoting and popularizing the fruit, encouraging its production, processing and marketing, in addition to promoting cultural and tourist activities (Auá Institute, 2024).

Previous research on cambuci has primarily focused on characterizing its bioactive and antioxidant compounds. Cambuci possesses a variety of bioactive compounds, each with potential health benefits, justifying the interest in the fruit (Tokairin et al., 2018). Many of these compounds have promising prospects for preventing or mitigating Non-Communicable Chronic Diseases (NCDs) and obesity and its complications (Donado-Pestana et al., 2021; Donado-Pestana et al., 2018). Some authors, such as De Carvalho et al. (2021), have even suggested the inclusion of fruit as an option for human dietary supplementation due to its high antioxidant nature.

Species of the Myrtaceae family, such as *C. phaea*, are also recognized in the literature for their antioxidant capacity (Teixeira et al., 2019; Santoro et al., 2022). These compounds help combat oxidative stress, delay or neutralize free radicals that can damage cells, and contribute to developing chronic diseases, such as cardiovascular diseases, cancer, and neurodegenerative diseases (Stafussa et al., 2021).

There is increasing interest from researchers and the food industry in the antioxidant activity of fruits, vegetables, and plants in general due to synthetic antioxidant products' suspected side effects and toxicity (Otero et al., 2020; Tokairin et al., 2018). Wczassek et al. (2019) attributed the antioxidant properties of cambuci to its bioactive compounds, such as phenolic compounds and L-ascorbic acid.

Investigating the antioxidant and biological properties of new Brazilian fruits, such as cambuci, can boost economic growth by helping to generate income and sustainability, bringing nutritional enrichment through food biodiversity, strengthening food and nutritional security (FNS) and fostering diversity menu culture (Medeiros et al., 2020; Silva et al., 2022). According to Santoro et al (2022), the fruit has multiple uses in its consumption, and can be consumed fresh or in industrialized products such as juice, liqueur, ice cream, mousse and cake, among other options.

Thus, through this study, we aim to attract nutrition researchers' attention to the possibilities and potential related to cambuci. This study focuses on the nutritional properties and bioactive and phytochemical composition of cambuci.

2. MATERIAL AND METHODS

2.1. Plant Material

The cambuci fruits were harvested in March-April 2022 from a commercial orchard at Campo Alto farm, located in the municipality of Araras, state of São Paulo, Brazil (22º23' S and 47º17' W, and 615 m altitude). A total of 2 kg of ripe cambuci fruits were collected manually, ensuring that only intact and good-quality fruits were selected. All analyses were performed in triplicate to guarantee the accuracy and reliability of the results.

2.2. Physicochemical and nutritional analysis

To calculate the weight of the whole fruit, longitudinal and transverse diameters, pulp yield, and peel percentage, two fruits were selected: one representing a small specimen and the other representing a large specimen.

The fresh weight of the whole fruit -was determined on an analytical balance (BEL - LW303I, Engineering, Italy), and the results are expressed in grams (g). The longitudinal and transverse diameters (LD and RD, respectively) -were measured with a digital caliper, and the results are expressed in millimeters (mm). Pulp yield and peel percentage - The fruits were carefully cut to separate the pulp from the peel and seeds. The separation was performed manually to ensure the complete removal of the pulp and minimize losses. The calculations were performed as follows:

$$\text{Pulp yield (\%)} = \frac{\text{weight of pulp}}{\text{total weight of fruit}} \text{ x } 100 \qquad \text{Equation 1}$$

$$\text{Pulp percentage (\%)} = \frac{\text{weight of peel}}{\text{total weight of fruit}} \text{ x } 100 \qquad \text{Equation 2}$$

The color was determined with a colorimeter (Chroma Metter CR-400) in which 5 color parameters were evaluated: L*, a*, b*, c* and h_{ab}*, according to the CIELAB color system (Jan, Panesar & Singh, 2018).

The moisture content was determined using method no. 925.26, the pH was measured using method no. 970.21, and a digital pH meter (Tecnal, Tec-CMP, Piracicaba, São Paulo, Brazil) was used. The titratable acidity (method no. 942.15) was determined by titration with 0.1 mol/L NaOH (AOAC, 2005). The soluble solids content (SSC) was determined by method no. 932.12 with a digital refractometer (Palette PR-101 Atago Co., Ltd., Tokyo, Japan) (AOAC, 2005).

Lipids were extracted in a Goldfish apparatus, using petroleum ether as a tapir extracting solvent (AOAC - 991.36, 2005). Proteins were determined by the Kjeldahl method, and the nitrogen to crude protein conversion factor adopted was 6.25, normally used to report proteins from fruits, berries and vegetables (AOAC - 2001.11). Carbohydrates, including total dietary fiber, were calculated using the following equation: carbohydrates (%) = 100 - (% moisture + % protein + % total lipids + % ash). Calories: Sum of proteins plus carbohydrates multiplied by the factor 4 (Kcal/g), added to the total lipid content, multiplied by the factor 9 (Kcal/g). The ash content was determined by the muffle incineration method at 550° (AOAC - 942.05, 2012). Minerals (iron, copper, manganese, magnesium, calcium and zinc): were determined by flame atomic absorption spectrophotometry, with dry digestion of the sample (AOAC 985.01, 2005).

To determine calcium and magnesium, lanthanum oxide was used to eliminate possible interference (AOAC, 2005). The ascorbic acid content was determined using the method described by Zambiazi (2010). The juice was extracted from the fruit and filtered, and ascorbic acid quantification was performed through titration using standard iodine and sodium thiosulfate solutions with starch as an indicator. The results were calculated using Equation 3 and are expressed in mg.100 g^{-1}.

$$\text{Vit C} = (V\,1 \times F\,1) - (V\,2 \times F\,2) \qquad \text{Equation 3}$$

where V1 is the volume of iodine used in the titration, V2 is the volume of thiosulfate used in the titration, and F is the solution correction factor.

2.3. Analysis of Bioactive Compounds

Total phenolic compounds were determined according to the methodology described by Swain & Hillis (1959), with some modifications. Briefly, 0.25 ml of the extract was mixed with 2.75 ml of 3% Folin-Ciocalteu solution. After resting for 5 minutes, 0.25 ml of 10% sodium carbonate solution was added, and the mixture was allowed to rest for 60 minutes in the dark at room temperature. The reading was carried out on a UV–Vis Bel UV-M51 spectrophotometer at 765 nm.

Flavonoids were determined according to Funari & Ferro (2006), with modifications. One milliliter of extract was reacted with 3 ml of ethanol/water and 200 µl of 2.5% aluminum chloride solution and kept at rest for 40 minutes. Absorbance readings were performed using a UV–Vis spectrophotometer (Bel UV-M51) at a wavelength of 415 nm. Quantification was performed using increasing concentrations of quercetin prepared in ethanolic solution (0 to 100 $mg.g^{-1}$).

Condensed tannins were determined by spectrophotometry, read at 500 nm, using the Vanillin-HCl method of Price, Scoyoc, and Butler (1978). First, 200 mg of sample was weighed, and 10 ml of 1% HCL in ethanol was added and left on a vibrating table for 2 hours. Then, it was centrifuged at 7000 rpm (Solab, SL-706) for 10 minutes, and the supernatant was stored under refrigeration until analysis.

Aliquots of 1 ml of the sample were then added to 5 ml of 1:1 Vanillin:HCl 8% solution, homogenized by vortex, and left to rest for 20 minutes in a water bath at 30ºC (Solab, SL-154). After cooling the sample, readings were taken at 500 nm on a UV spectrophotometer (Bel UV-M51). The total concentration of condensed tannins was calculated using a catechin standard curve (0 - 0.0010 $g.ml^{-1}$).

Hydrolysable tannins were determined using the methodology described by Brune, Hallberg, and Skanberg (1991). A sample of 0.5 g was weighed, and 25 ml of ethanol was added and filtered through cotton wool. 0.3 ml of the extract and 8 ml of the FAS solution were used. The samples were read in a spectrophotometer at a wavelength of 680 mn. The concentration was calculated using a standard curve of ethanolic gallic acid solutions (20 - 100 $mg.L^{-1}$).

Chlorophyll was determined using the methodology of Harmut and Lichtenthaler (1987). To do this, 0.5 g of frozen pulp was weighed, 5 mL of 80% (v/v) acetone was added, vortexed for 60 seconds, and centrifuged (Solab, SL-706) for 5 minutes at 3000 rpm and then the supernatant was transferred to a 25 ml flask and the volume was adjusted. The extract was subjected to absorbance reading (646 and 663 nm) on a UV-Vis spectrophotometer (Bel UV-M51). To determine total chlorophylls, equations 4, 5, and 6:

$$\text{Chl Total} = 7.15 * (A663) + 18.71 * (A646) \qquad \text{Equation 4}$$

$$\text{Chl a} = 12.25 * (A663) - 2.79 * (A646) \qquad \text{Equation 5}$$

$$\text{Chl b} = 21.50 * (A646) - 5.10 * (A663) \qquad \text{Equation 6}$$

For the analysis of carotenoids, the samples were dissolved in petroleum ether, and the total carotenoids were quantified (Rodriguez-Amaya, 2001) using a UV-Vis Lambda 25 spectrophotometer (Perkin Elmer) by reading the maximum absorption wavelength (450 nm). The results were calculated using Equation 7:

$$\text{Concentration} = \frac{\text{A x y(mL)x } 10^6}{A_{1cm}^{1\%} \text{ x } 100} \qquad \text{Equation 7}$$

2.4. Antioxidant Activity

To obtain the extracts, 0.5g of the sample was weighed in 20 mL of ethanol and 20 mL of water and then stirred at 25º C for 24 hours in a water bath. The ABTS radical (2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid)) was determined as described by Rufino et al. (2007). An aliquot of 30 µL of each dilution of the extract was transferred to falcon tubes with 3.0 mL. The reading was performed at a wavelength of 734 nm, and the results were expressed in µMmol of Trolox per gram of dry sample.

The iron-reducing capacity (FRAP) was determined as described by Rufino et al. (2006). An aliquot of 90 µL of each dilution of the extract was transferred to falcon tubes with 270 µL of distilled water and 2.7 mL of FRAP reagent. The reading was carried out at a wavelength of 595 nm, and the results were expressed in µM ferrous sulfate per gram of dry sample.

2.5. Analysis of Volatile Compounds

The materials were analyzed on a Shimadzu Nexis GC2030 gas chromatograph (Shimadzu Corporation, Kyoto, Japan) coupled to a mass spectrometer, equipped with an SH-Rxi-5Sil MS column (30 m × 250 µm, 0.25 µm). The samples were previously heated via headspace at 80 ºC for 30 min, and a volume of 1.0 mL was injected into the chromatograph. The split mode was used with a ratio of 10:1 with an equilibrium time of 3 minutes. The oven temperature programming was initially maintained at 50 °C for 1 minute, the heating ramp was from 5 °C/min to 150 °C, then increased to 10 °C/min to 240 °C. Helium 5.0 was used as the carrier gas, with a pressure of 4.7 psi, a flow rate of 0.94 mL/min, and a linear speed of 35.0 cm/s. The temperature of the injector, interface, and ion source was maintained at 250°C. The mass spectrometer operated in scan mode, recording ions in the range of 20 to 400 m/z with a scan time of 150 ms, and was compared with reference compounds from the NIST 17 library.

2.6. Statistical analysis

The data were presented as mean ± standard deviation (SD). Pearson's correlation coefficient was used to determine the strength of the correlation between the results of bioactive compounds and antioxidants. Student's t-test was used to evaluate the results of alcoholic and aqueous extractions of antioxidant activity ($p \leq 0.05$). Statistical analyses were performed using Statistica 8.0 software (StatSoft Inc., South America, Tulsa, OK, USA).

3. RESULTS AND DISCUSSION

3.1. Physicochemical and nutritional analysis

The cambuci presents variations in its weight of 36.17 - 109.4 g (Table 1). These variations occur frequently and are also reported by other authors, such as Tokairin et al. (2018), who obtained data from 59 accessions and observed a weight variation between 26.72 to 63.02 g. The same occurred regarding the size of the fruit, varying between 3.9 - 4.9 cm in length and 3.8 - 6.7 cm in diameter. Morphologically, it is common for variations to occur, both in the shape and size of the fruits, resulting from environmental, genetic, or cultivation conditions (Ûchoa et al., 2020). Furthermore, cambuci is propagated mainly through seeds, leading to more significant genetic variability, justifying these differences (Tokairin et al., 2018).

Table 1 - Physicochemical and nutritional characterization of cambuci fruit

Analysis	**Results**
Moisture (%)	86.0 ± 0.00
pH	3.0 ± 0.02
TA(%)	1.2 ± 0.00
ºBrix	3.4 ± 0.11
Lipid (%)	0.7 ± 0.16
Protein (%)	0.3 ± 0.00
Carbohydrate (%)	12.2 ± 0.00
Calories (kcal/100 g)	56.1 ± 0.16
Ashes (%)	0.8 ± 0.00
Zinc (mg.kg^{-1})	7.1 ± 0.52
Iron (mg.kg^{-1})	14.5 ± 0.11
Copper (mg.kg^{-1})	2.3 ± 0.11
Manganese (mg.kg^{-1})	5.9 ± 0.20

Calcium (mg.kg^{-1})	0.5 ± 0.00
Magnesium (mg.kg^{-1})	0.6 ± 0.42
Acid Ascorbic (mg.100 g^{-1})	105.9 ± 8.70
Weight (g)	36.2 – 109.40
AL (cm)	3.9 – 4.90
AD (cm)	3.8 – 6.70
Yield (%)	91.8 – 92.40
Peel (%)	13.9 – 14.80
L*	48.3 ± 0.40
a*	1.9 ± 0.11
b*	8.7 ± 0.60
h°	35.1 ± 7.20
C*	2.2 ± 0.07

The values are presented as the means (± standard deviation, n = 3); AT = titratable acidity; SSC = soluble solids content; *AL = medium length; AD = average diameter.

The fruit yield was high, ranging from 91.8 - 92.4% (Table 1), which also corroborates the study by Tokairin et al. (2018), who found a percentage of 89.34%. Other studies also emphasize the high yield of cambuci, such as Teixeira et al. (2019) and Dias et al. (2018). They observed that, besides the high yield, cambuci has a distinctive flavor that makes it suitable for diluting its pulp, an exciting factor for food industries.

The percentage of peel varied from 13.9 to 14.76%, values higher than those found by Tokairin et al. (2018) of 6.66%. These amounts may vary depending on the size of the fruit, the stage of ripeness and the specific variety (Donado-Pestana et al., 2018). Both studies used the manual method to remove the peels, which can generate variation depending on the care in execution, which depends on the precision of the researcher. The fruits analyzed by Tokairin et al (2018) come from the same state (São Paulo) as the present study, but they are from different municipalities, which may justify this type of variation. Heavier and thicker skins can provide greater protection to the fruit, but negatively affect its yield (Ûchoa et al., 2020).

The color of the fruits presented an a* of 1.9 and b* of 8.7 (Table 1), tending towards orange-green (Figure 1). Dias et al. (2018) obtained slightly different results in their study, with cambucis from the Serra da Mantiqueira region, also in the state of São Paulo. Its values were a* (3.9) and b* (10.5), suggesting a slightly greener fruit. Regarding luminosity (L*), chromaticity (C) and hue angle (h_{ab}), values of 48.3, 2.2 and 35.1 were obtained, respectively, indicating a yellowish-green color. Variations in shades occur frequently and may be due to factors related to solar incidence, temperature, rainfall or stage of fruit maturation (Tokairin et al., 2023; Bianchini et al., 2020). Furthermore, according to data from the National Institute of Meteorology (INMET), the municipality of Araras, the region where the samples came from, has a hotter and drier climate compared to Serra da Mantiqueira, which has a colder and more humid climate, especially in winter. , a factor that may also justify these differences in color.

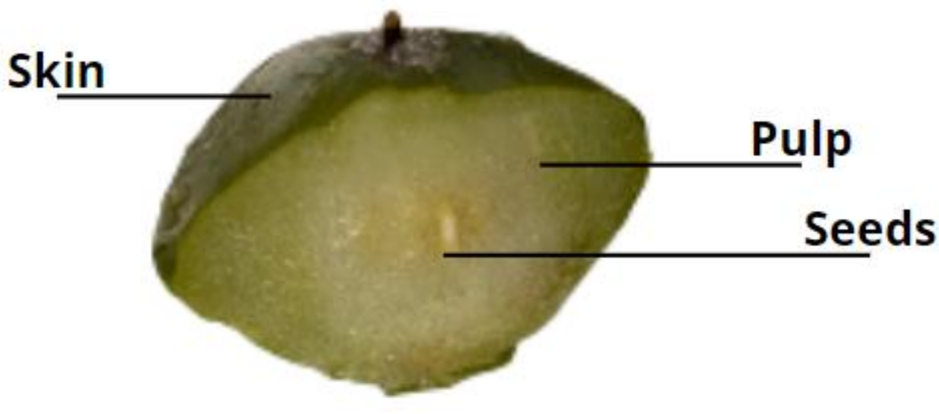

Figure 1. Cambuci fruit split in half, showing its pulp, skin and seeds.

Cambuci is a fruit characterized sensorially by being juicy; this aspect is evidenced in Table 1 by its high moisture content (86.04%). This value corroborates other findings found in the literature, such as those of Donado-Pestana et al. (2018), which demonstrated 85-89% moisture. Paes et al. (2019) discussed how this high moisture (above 80 g/100 g w.b.) may be associated with the low consumption of cambuci because it results in a short shelf life.

Cambuci pulp demonstrated low pH values, as indicated in Table 2. Studies conducted by Dias et al. (2018) and Paes et al. (2019) highlighted acidic pH as a limiting factor when consuming fresh fruit compared to lemon. Neto et al. (2018) conducted a study with Galician lemon (*Citrus aurantifolia Swingle*) at different stages of maturation. Average pH values of 2.69 were obtained.

Table 2 - Total bioactive compounds from *Campomanesia phaea.*

Total compounds	Results
Phenolic (mg.g^{-1} GAE)	545.3 ± 47.70
Flavonoids (mg quercetin.g^{-1})	1.3 ± 0.00
Condensed Tannins (mg.g^{-1})	0.4 ± 0.20
Hydrolyzable Tannins (mg.g^{-1})	26.4 ± 7.30
Carotenoids (mg β-carotene.g^{-1})	9.2 ± 2.60
Total Chlorophyll (mg.g^{-1})	41.8 ± 8.35
Chlorophyll a (mg.g^{-1})	23.2 ± 6.3
Chlorophyll b (mg.g^{-1})	18.6 ± 2.0

GAE = gallic acid equivalents;Cya-chloro = cyanidin-3-O-rutinoside chloride; EC = equivalent catechin;

Although low pH values can be unfavorable for direct consumption, they can be advantageous in manufacturing industrial products such as sweets and jellies. Acidity, in addition to hindering the development of microorganisms, minimizes the need for excessive thermal processing (Neto et al., 2018).

Likewise, the titratable acidity of cambuci was low at 1.21% and was the quality attribute that suffered the slightest variation between samples (standard deviation - 0.0). Tokairin et al., (2018) compare cambuci as a variant between the flavor of sour passion fruit (*Passiflora edulis Sims*) (2.78%) and 'Pêra' orange (*Citrus sinensis (L.) Osbeck*) (0.95%) which are also fruits recognized for being acidic.

The total soluble solids of cambuci was low at 3.43 °Brix (Table 2). This total soluble solids can be affected by the degree of ripeness of the fruit or even by the region in which it is cultivated. Dias et al. (2018) analyzed cambuci coming from different accesses of Serra da Mantiqueira (the mountainous mountain range of Minas Gerais) and found values of 1.33 - 2.67 °Brix in their study.

The lipid, protein, and carbohydrate contents of cambuci were also analyzed, which were relatively low (Table 2). No recent cambuci data were found to enrich the discussion, however the study by Santos et al (2020) with flour from jabuticaba extract (*Plinia cauliflora*) (a fruit from the same family as *Campomanesia phaea*), obtained values of 0.6% of lipids, 12.13% of protein and 62.13% of carbohydrates. In the Food Composition Table (TACO) (Ministry of Health, 2011), the caloric value of jabuticaba (58 kcal/100g) is similar to that of cambuci in this study (56.12 kcal/100g).

The ash content was 0.82%, corroborating the amount of minerals contained in the fruit (Zn: 7.15 mg.kg^{-1}; Fe: 14.5 mg.kg^{-1}; Cu: 2.30 mg.kg $^{-1}$, Mn: 5.87 mg.kg^{-1}; Ca: 0.50 mg.kg^{-1}; Mg: 0.60mg.kg^{-1}). There are no recent data on this mineral composition in the literature.

However, when compared with uvaia (*Eugenia pyriformis*), we realize that it has a higher amount of ash (2.18%) and consequently minerals, such as copper (9.9 mg.kg^{-1}) and manganese (20.6 mg.kg^{-1}) (Menezes et al., 2021).

Ascorbic acid, likewise, helps neutralize free radicals and protect cells against oxidative stress, in addition to its effect on immunity and its anti-allergic action (Wczassek et al., 2019; Jafari et al., 2019). Tokairin et al. (2018) and Dias et al. (2018) obtained 72.16 mg.100g^{-1} and 115.44 mg.100g^{-1} in their studies, respectively. Cambuci meets the daily vitamin C recommendations for adults, 75 to 90 mg/day (DRI, 2000). Orange (*Citrus sinensis*), a fruit popularly known for being a source of ascorbic acid, has, according to TACO (Ministry of Health, 2011), 53.7 mg.100g^{-1} of vitamin C. These aspects favor the inclusion of cambuci in the dietary routine as a source of antioxidants and vitamin C (Santoro et al., 2022).

3.2 Bioactive Compounds

Cambuci has a variety of bioactive compounds, and each of them has potential health benefits that may justify the increased interest in this fruit (Tokairin et al., 2018). Many of these compounds have a promising perspective to act in preventing or mitigating NCDs in addition to obesity and its complications (Donado-Pestana et al., 2021; Donado-Pestana et al., 2018). Some authors, such as De Carvalho et al., (2021), even bring up the possibility of including the fruit as an option for human dietary supplementation due to its high antioxidant nature. Table 2 shows the total bioactive compounds of cambuci.

Phenolic compounds have increasingly attracted the attention of researchers due to their ability to prevent health problems, such as degenerative diseases, inflammatory processes, and cardiovascular disorders (Wczassek et al., 2019). The value found in the present study is similar to that reported by Tokairin et al. (2018) of 617.90 mg GAE g^{-1}. Donado-Pestana et al. (2018), in their study on the fruits of the Myrtaceae family, classify cambuci as a significant source of biologically active polyphenols. The research highlighted that these phenolic compounds, present in large quantities in cambuci, are known for their antioxidant and anti-inflammatory properties, which can contribute to preventing and combating obesity and its complications. The study focused on the action of polyphenols and demonstrated that these compounds have the ability to modulate metabolic processes related to weight gain, inflammation and insulin resistance, reinforcing the importance of cambuci in promoting health.

Flavonoids are active compounds that also belong to the group of phenolic compounds. Donado-Pestana et al. (2018) reported the presence of flavonoids in cambucizeiro leaves, along with tannins and saponins. Castelucci et al. (2020) found 1.40 mg of quercetin.g^{-1}, a value very close to that identified in the present study. According to Teixeira et al. (2019) the presence of flavonoids may indicate a possible anti-obesity effect due to the changes in the intestinal microbiota that they promote. Stafussa at al. (2021) reported in their study with cambuci the presence of quercetins and kaempferols. According to Donado-Pestana et al. (2018), these compounds have antidiabetic potential and can reduce postprandial glycemia.

Also belonging to the group of bioactive compounds, tannins are polyphenols known for their property of binding to proteins and other compounds, which gives them an essential role in the sensorial aspect of astringency fruits (Tokairin et al., 2023). They can be divided into condensates and hydrolyzable. Table 3 presents that the values of hydrolyzable tannins were higher than those of condensates. According to Tokairin et al. (2023) these differences may occur due to the polymerization of tannins during fruit ripening, manifesting a decrease in astringency, an attractive factor in the sensory aspect.

Carotenoids are also bioactive compounds that play a considerable role in preventing some diseases (Castelucci et al., 2020). They not only contribute to the pigmentation of plants, fruits and vegetables, but also have anti-inflammatory, anti-diabetic, anti-cancer, immunomodulatory and neuroprotective properties (Nabi et al., 2020). Castelucci et al. (2020) found 0.00299 mg of β-carotene/g^{-1} of carotenoids in their study with C. phaea; however, this value may be underestimated, as the authors used diluted fruit pulp, in a proportion of two parts of fruit to one part of water (2:1).

In the present study we found 9.2mg β-carotene.g-1. β-carotene is a type of carotenoid that acts as an antioxidant in lipid environments. According to de Paulo Farias et al. (2020) it has the ability to neutralize reactive species, preventing damage to lipoprotein membranes. Donado-Pestana et al. (2018) also attributed the antioxidant potential of cambuci to the presence of bioactive molecules, such as carotenoids.

Cambuci presented high levels of chlorophyll, with a predominance of chlorophyll a over chlorophyll b, reflecting its characteristic green color. These values indicate a significant concentration of pigments, especially in the skin, which tends to remain green for longer during ripening. However, studies such as that by Tokairin et al. (2023), on the ripening stages of Campomanesia phaea, suggest that, as the fruit ripens, a progressive degradation of chlorophyll occurs, resulting in a slightly yellowish color. According to the authors, this process is mediated by the action of the enzyme chlorophyllase or by changes in pH and oxidative systems, which promote the degradation of chlorophyll pigments. Thus, the color of cambuci can be an important visual indicator of its ripening stage, influencing both its acceptance by consumers and its nutritional quality.

The dissemination of bioactive compounds found in little-consumed fruits, such as cambuci, can positively influence interest in their consumption and highlight their viability for industrial applications. The distinct sensory properties of this fruit offer a crucial advantage for this to occur, thus contributing to its acceptance and incorporation into various food products (Teixeira et al., 2019; Paes et al., 2019). These findings highlight the importance of exploring and promoting the nutritional and functional potential of fruits from the UFP group as part of a comprehensive strategy to promote a healthy and diverse diet.

3.3 Antioxidant Properties

The antioxidant activity was evaluated in the present study by 2 different in vitro methods (Table 3). It was observed that the inhibition techniques using ABTS and FRAP presented different results in terms of antioxidant capacity, between themselves and between the extracts (alcoholic or aqueous).

Table 3.: Discriminatory variables between different types of extracts to detect the antioxidant activity of *Campomanesia phaea*.

Extract	**Methods**		**p-value**
	ABTS (mmol Trolox.g^{-1})	**FRAP (mmol Trolox.g^{-1})**	
Ethanolic	326.2 ± 8.8	162.4 ± 5.0	<0.001[a]
Aqueous	275.1 ± 29.0	262.2 ± 21.6	0.569[a]

[a] Independent Student's t-test.ABTS = 2,2´-azinobis (3-etilbenzotiazolina-6-sulfonic acid); FRAP = Ferric Reducing Antioxidant Power

The study by Castelucci et al., (2020) evaluated the antioxidant activity of cambuci, using the ABTS method in ethanolic medium and obtained 32.06 µmol Trolox g^{-1}, a value below that found in this study (326.2 µmol Trolox g-1). In this case, however, the authors used cambuci added with 2 parts of water, which may have interfered with the result. Stafussa et al., (2021) also evaluated cambuci using ABTS and obtained a result of 371.60 µmol trolox g^{-1}, a value close to that found in this study. Regarding the FRAP method, some conventional fruits, such as banana (*Musa sapientum*) and mango (*Mangifera indica*), presented significantly lower values, of 24.7 µmol Fe^{2+}/g and 69.9 µmol Fe^{2+}/g, respectively, compared to cambuci (Santos et al., 2020). In addition, other fruits from the same family, such as guava (*Psidium guajava*), uvaia (*Eugenia pyriformis*) and jabuticaba (*Plinia cauliflora*), were also evaluated, presenting values of 22.4 μmol Fe^{2+}/g, 41 μmol Fe^{2+}/g and 71.2 μmol Fe^{2+}/g, respectively (Santos et al., 2020; Farias et al., 2020). Comparison with other fruits from the same family and with conventional fruits highlights the antioxidant superiority of cambuci.

Authors such as Stafussa et al. (2021) highlight the importance of consuming fruits with high antioxidant activity due to their potential health benefits. In their study, they draw attention to the in vitro digestion process where there is a significant reduction in the antioxidant activity of fruits, especially in the gastric and intestinal phases. Using the ABTS method, after undergoing in vitro gastric digestion, they obtained a reduction of approximately 54%, and after in vitro intestinal digestion, there was a 10.56% reduction in the bioavailability of cambuci antioxidants, going from 371.6 μmol trolox g-1 to 39.3 μmol trolox g^{-1}. This observation is important because many of the benefits attributed to antioxidants can be reduced or altered during digestion, impacting the bioavailability of these compounds and reinforcing the importance of consuming fruits with this high potential.

Furthermore, to ensure the antioxidant capacity, it is important to use more than one protocol, due to the diversity of chemical matrices and the varied sensitivity of in vitro tests, so that the antioxidant activity of the fruit can be inferred (Castelucci et al., 2020). In the present study, the ABTS and FRAP methods presented different results between themselves and between the solutions used (Table 3).

The results measured by the FRAP method presented higher values in the extraction performed in aqueous medium. This may occur due to the tendency of polar solvents, such as water, to extract larger amounts of polyphenols and flavonoids (Bezerra et al., 2022). Furthermore, when we compare the ABTS and FRAP methods, both with aqueous extracts, we observed that there is no significant difference between them. This fact may reiterate the extraction in aqueous medium as being probably more reliable for this raw material. Although the results are not significantly different, it is important to emphasize the usefulness of replicating the experiment with the fruit in different conditions or samples from other locations to confirm the equivalence of the methods.

The correlation analyses between the antioxidant activity and the bioactive compounds of cambuci (Campomanesia phaea) revealed significant associations. In the case of Pearson's correlation between the antioxidant activity assessed by the ABTS method in ethanolic extract and the carotenoid content, a strong and significant negative correlation of -0.99 ($p < 0.05$) was observed (Figure 2a). This result suggests that the increase in carotenoid concentration is associated with the decrease in the antioxidant activity measured by ABTS, evidencing an inverse relationship between these variables.

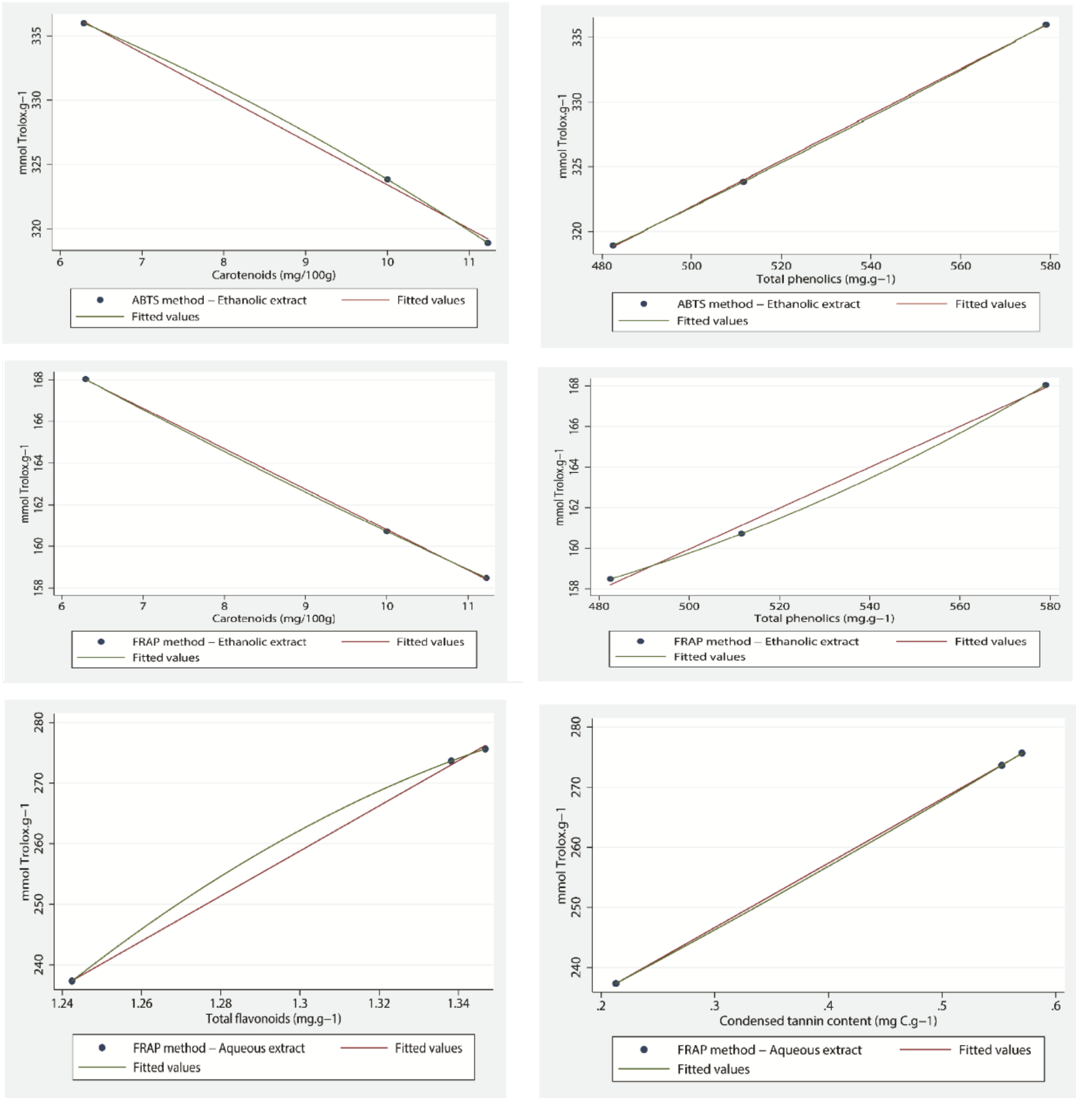

Figure 2. Graphs of correlation analyses between the antioxidant activity methods with their different extracts (ethanolic or aqueous) and the bioactive compounds (carotenoids, phenolics, flavonoids and condensed tannins) .

On the other hand, the correlation between ABTS in ethanolic extract and phenolic compounds resulted in a positive correlation of 0.99 ($p < 0.01$) (Figure 2b), indicating a strong direct relationship. This presupposes that phenolic compounds may play a relevant role in the antioxidant activity of the extract, reinforcing the importance of these substances as the main responsible for the antioxidant capacity of cambuci. Some other studies also discuss this association, but without providing statistical data on the correlation, such as Tokairin et al. (2018) and Wczassek et al. (2019).

When performing the analyses with the FRAP method in ethanolic extracts, a significant negative correlation of -0.99 ($p < 0.05$) (Figure 2c) was observed between the antioxidant activity and the carotenoid content. This behavior is similar to that observed with ABTS, suggesting that carotenoids can act in a similar way in different antioxidant systems. In the correlation between FRAP and phenolic compounds, a significant positive correlation of 0.99 ($p < 0.05$) was recorded (Figure 2d), once again reinforcing the central role of phenolics in the antioxidant activity of the fruit. Finally, FRAP analysis in aqueous extracts showed significant positive correlations with both flavonoids (0.99; $p < 0.05$) (Figure 2e) and condensed tannins (1.00; $p < 0.05$) (Figure 2f). These findings highlight the importance of these compounds in the antioxidant capacity of the aqueous extract, with tannins presenting the highest correlation, indicating their strong contribution to the bioactivity of cambuci. Tokairin et al. (2023) reinforce this in their study, showing that tannins have great antioxidant potential and this is due to their molecular weight and the high degree of hydroxylation of their aromatic rings. The same happens with flavonoids, which, in addition to being correlated with antioxidant activity, according to Stafussa et al. (2021), have high bioaccessibility, an interesting factor when it comes to bioactive and antioxidant compounds.

The antioxidant activity of cambuci thus proves to be a valuable resource due to its possible ability to neutralize or delay the reactions of free radicals, responsible for oxidative degradation in the body. In addition, studies indicate that its antioxidant activity can help combat inflammatory processes, chronic non-communicable diseases and strengthen the immune system (Donado-Pestana et al., 2021; Stafussa et al., 2021). To better understand and explore its effects on the human body, more research, also using in vitro methods, is still needed.

3.4 Volatile Composition

The profile analysis of volatile and aromatic compounds from cambuci identified a total of 52 compounds, as presented in Table 4. Z-3,7-dimethyloctatriene was responsible for 17.82% of the total area of compounds, followed by α-pinene (15 .42%) and D-Limonene (14.26%), corroborating the fresh/citrus, pine/cedar, and citrus aromas.

Some of these compounds, such as d-limonene, have been studied due to their therapeutic properties. d-limonene is a monoterpene, a class of organic compounds found in essential oils from citrus fruits, recognized for its expectorant and anticancer properties (Souza et al., 2020).

Table 4 - Description of the Volatile and Aromatic Compounds of *Campomanesia phaea*

CN	Name	CAS	% Area	Aroma	Classification	New Compounds
1	Pentanal	110-62-3	2.01	Fruity	Aliphatic aldehyde	Silva et al., 2019 (Uvaia)
2	Hexanal	66-25-1	4.58	Gram, herbaceous	Aliphatic aldehyde	Silva et al., 2019
3	Furfural	98-1-1	0.64	Almonds, smoke	Aliphatic aldehyde	Yes
4	(1R)-2,6,6-Trimetilbiciclo [3.1.1]hept-2-eno	7785-70-8	15.42	Pine, cedar	Alpha-pinene	Yes
5	Furfural	10410-20-5	0.33	Caramel	Ester	Yes

6	Camphene	79-92-5	3.58	Wood, pine, herbal	Terpene	Yes
7	2-Heptenal, (E)-	18829-55-5	0.71	Grass, green leaves, herbal	Unsaturated aliphatic aldehyde	Yes
8	Bicyclo[3.1.1]heptane, 6,6-dimethyl-2-methylene-, (1S)-	18172-67-3	1.70	Cloves, black pepper, cinnamon	Sesquiterpene	Yes
9	β-Myrcene	123-35-3	1.15	Herbs, citrus fruits, spices	Monoterpene	Silva et al., 2019
10	Octanal	124-13-0	0.80	Slightly sweetened	Alkane	Silva et al., 2019
11	α-Phellandrene	99-83-2	2.72	Fresh, herbal	Terpene	Tokairin et al., 2023 Silva et al., 2019
12	Acetic acid, hexyl ester	142-92-7	0.48	Fruity	Hexyl acetate	Silva et al., 2019
13	α-Terpinene	99-86-5	2.13	Sweet	Cumene	Yes
14	p-Cymene	99-87-6	1.29	Herbal, earthy	Hydrocarbon	Yes
15	D-Limonene	5989-27-5	14.26	Citric	Monoterpene	Tokairin et al., 2023 Silva et al., 2019
16	Eucalyptol	470-82-6	6.63	Fresh, herbal	Monoterpene	Tokairin et al., 2023 Silva et al., 2019
17	β-cis-Ocimene	3338-55-4	17.82	Fresh, citrus	Terpene	Yes

18	γ-Terpinene	99-85-4	1.40	Citrus, spicy, earthy	Terpene	Yes
19	2-Carene	554-61-0	1.45	Fresh, herbal	Monoterpene	Yes
20	Linalool	78-70-6	0.88	Sweet, fresh floral	Terpenoid	Tokairin et al., 2023
21	Nonanal	124-19-6	0.82	Fresh, citrus	Aliphatic aldehyde	Silva et al., 2019
22	Borneol	507-70-0	0.24	Fresh, herbal	Bicyclic alcohol	Yes
23	Terpinen-4-ol	562-74-3	0.16	Fresh, herbal	Monoterpenoid	Tokairin et al., 2023
24	(R)-α,α,4-trimethylcyclohex-3-ene-1-methanol	7785-53-7	0.86	Pine-like	Monocyclic alcohol	Yes
25	2-Decenal, (E)-	3913-81-3	0.28	Citric	Aliphatic aldehyde	Yes
26	α-Cubebene	17699-14-8	0.12	Spicy, woody, hot	Monocyclic hydrocarbon	Tokairin et al., 2023 Silva et al., 2019
27	Ylangene	14912-44-8	0.43	Floral, woody	Sesquiterpene hydrocarbon	Yes
28	α-Copaene	3856-25-5	3.94	Woody, spicy, earthy	Sesquiterpene hydrocarbon	Yes
29	1H-Cycloprop[e]azulene, 1a,2,3,4,4a,5,6,7b-octahydro-	489-40-7	0.27	Chamomile, yarrow	Azulenes	Yes

	1,1,4,7-tetramethyl-, [1aR-(1aα,4α,4aβ,7bα)]-					
30	Caryophyllene	87-44-5	2.75	Spicy, earthy	Sesquiterpene	Yes
31	α-Guaiene	3691-12-1	0.14	Woody, earthy, spicy	Sesquiterpene	Yes
32	(1R,9R,E)-4,11,11-Trimethyl-8-methylenebicyclo[7.2.0]undec-4-ene	68832-35-9	0.72	Woody, earthy, spicy	Sesquiterpene	Yes
33	(1S,4aR,7R)-1,4a-Dimethyl-7-(prop-1-en-2-yl)-1,2,3,4,4a,5,6,7-octahydronaphthalene	52026-55-8	0.21	Woody, earthy, spicy	Sesquiterpene	Yes
34	Humulene	6753-98-6	0.90	Earthy, herbal	Sesquiterpene	Tokairin et al., 2023 Silva et al., 2019
35	(1R,9R,E)-4,11,11-Trimethyl-8-methylenebicy	68832-35-9	1.48	Woody, earthy, spicy	Sesquiterpene	Yes

	clo[7.2.0]undec-4-ene					
36	(4aR,8aS)-4a-Methyl-1-methylene-7-(propan-2-ylidene)decahydronaphthalene	58893-88-2	1.00	Pepper, spices	Sesquiterpene	Yes
37	α-Amorphene	483-75-0	0.27	NA	Hydrocarbons	Yes
38	Isopropyl tetrahydronaphthalene	473-14-3	0.17	NA	Hydrocarbon	Yes
39	β-Selinene	17066-67-0	1.03	Woody, earthy, spicy	Sesquiterpene	Tokairin et al., 2023 Silva et al., 2019
40	(+)-Ledene	21747-46-6	0.63	Woody, earthy, spicy	Sesquiterpene	Yes
41	α-Guaiene	3691-12-1	1.05	Woody, earthy, spicy	Sesquiterpene	Yes
42	Naphthalene	58893-88-2	0.32	woody, floral, earthy	Sesquiterpene	Yes
43	γ-Muurolene	30021-74-0	0.26	Woody, earthy, spicy	Sesquiterpene	Silva et al., 2019
44	1-Isopropyl-4,7-dimethyl-1,2,3,5,6,8a-hexahydronaphthalene	16729-1-4	0.98	NA	Hydrocarbon	Yes

45	Zonarene	41929-5-9	0.25	NA	Hydrocarbon sesquiterpenes	Yes
46	Naphthalene	16728-99-7	0.08	Floral, fruity, fresh	Hydrocarbon	Yes
47	(-)-Globulol	489-41-8	0.10	Fresh, woody, herbaceous	Sesquiterpene	Yes
48	Guaiol	489-86-1	0.08	Fresh, woody, earthy	Sesquiterpene	Yes
49	2-((4aS,8R,8aR)-4a,8-Dimethyl-3,4,4a,5,6,7,8,8a-octahydronaphthalen-2-yl)propan-2-ol	194607-96-0	0.12	NA	Hydrocarbon	Yes
50	τ-Muurolol	19912-62-0	0.09	Woody	Sesquiterpene	Yes
51	τ-Cadinol	5937-11-1	0.21	Woody, earthy, spicy	Sesquiterpene	Yes
52	α-Guaiene	3691-12-1	0.06	Woody, earthy, spicy	Sesquiterpene	Yes

*Compound number (CN), unique record number at the Chemical Abstracts Service (CAS) database, an American Chemical Society division. Information not found in the literature was identified as NA.

A wide variety of compounds can be observed in the structure of cambuci, most of them belonging to the class of terpenes (38.46% sesquiterpenes and 21.15% monoterpenes), followed by aldehydes (11.54%) and hydrocarbons (hydrocarbons). aromatics: 7.69% and cyclic hydrocarbons: 1.92%). Descriptions of the profile of volatile organic compounds in cambuci are scarce. The only study found was that of Tokairin et al. (2023), who reported 27 compounds distributed in terpenes (59.26%), esters (37.04%) and aldehydes (3.70%).

In other studies, with members of the Myrtaceae family, such as uvaias (*Eugenia pyriformis Cambess*), Silva et al. (2019) identified 77 compounds, the majority of which were also terpenes (46.75%), followed by esters (29.87%) and aliphatic alcohols (9.09%). Costa et al. (2020) also identified terpenes in pitanga (*Eugenia uniflora*) as the main constituents, representing 42.7% of the total volatile formation.

Our results suggest that cambuci is a natural source of terpenes (59.61%), which may favor its use by the food and pharmaceutical industries. Terpenes are an important class of organic compounds, which have been increasingly studied for their aromatic and medicinal properties (Silva et al., 2019; Shaghaghi, N. 2020).

In this study, several compounds were identified in cambuci for the first time. Eight of these compounds were previously reported by Tokairin et al. (2023). Thirteen of them were documented by Silva et al. (2019) in their study with uvaia. This discovery expands the chemical profile of cambuci and highlights its potential for future research into bioactive compounds and their health benefits.

Despite the study by Tokairin et al. (2023) also occurred with cambuci, the chemical composition and concentration of the compounds may vary depending on the geographic location of the accessions. In their study, the authors reported that they observed butanoic acid, linalool, eucalyptol and ÿ-terpineol in higher concentrations.

With the diversity of volatile compositions presented, it is unlikely that it will be possible to determine the impact of each identified compound on fruit aroma. A suggestion for future research would be through gas chromatography-olfactometry (GC-O), as this analytical technique allows us to distinguish which compounds are most important for the sensory profile of the fruit (Egea et al., 2021).

Knowing aroma compounds can help in the formulation of food products, beverages and fragrances that replicate or use the aroma of cambuci. Souza et al. (2020) state that the identification of these compounds is crucial for the food, flavor and pharmaceutical industries, due to their proven antioxidant and antimicrobial properties.

4. CONCLUSION

Cambuci, with its rich composition of bioactive compounds, can be included in the dietary routine as a potential functional food. Its physical-chemical qualities may favor its use in the food industry due to its high yield. Their nutritional components give them high antioxidant capacity, which can contribute to human health. Furthermore, its diverse volatile composition can also meet different consumer demands, favoring its acceptance. Unpublished information provided in this article favors the continuation of studies on cambuci. Its use can benefit consumer health and is a positive aspect of the economy and the environment.

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10. CONSIDERAÇÕES FINAIS

O cambuci enfrenta o desafio de ser pouco conhecido pelo público em geral, mesmo em regiões onde é endêmica. Além disso, o fato da espécie encontrar-se em risco de extinção agrava ainda mais sua escassa presença no mercado.

O conhecimento mais amplo sobre suas propriedades nutricionais, bioativas e sensoriais pode impulsionar a demanda por essa fruta nativa, contribuindo diretamente para a segurança alimentar ao diversificar a dieta com uma PANC rica em nutrientes. Além disso, o fortalecimento do consumo do cambuci resgata tradições culturais, conectando as pessoas às suas raízes alimentares e valorizando o patrimônio natural da Mata Atlântica. O incentivo ao cultivo do cambuci em sistemas agroflorestais, especialmente por pequenos produtores e sem o uso de agrotóxicos, não apenas protege o meio ambiente, promovendo a conservação da biodiversidade, mas também gera uma cadeia produtiva mais sustentável, com impacto positivo na economia local. Dessa forma, o cambuci se apresenta como uma alternativa que une saúde, cultura e sustentabilidade, contribuindo para práticas agrícolas mais responsáveis e o fortalecimento de comunidades rurais.

Este estudo visou contribuir para a valorização do cambuci, não apenas destacando suas qualidades nutricionais e bioativas, mas também trazendo à tona a necessidade urgente de ações de conservação e de incentivo ao seu uso.

Durante a pesquisa, foram revisados os aspectos nutricionais, físico-químicos e a composição bioativa do fruto, comprovando que o cambuci é uma fonte rica em compostos que desempenham um papel importante na sua alta capacidade antioxidante. No estudo experimental inédito, foi feita uma correlação entre os métodos de atividade antioxidante em diferentes extratos (etanólicos e aquosos), evidenciando a eficiência de ambos na extração de compostos bioativos. Além disso, a análise dos compostos voláteis e aromáticos destacou o potencial sensorial do fruto, o que pode ser explorado para ampliar seu apelo comercial e gastronômico.

Esses achados reforçam a importância de se promover maior conhecimento sobre o cambuci e incentivar sua utilização em produtos alimentícios e cosméticos, valorizando assim uma fruta que, apesar de nativa, é subaproveitada. Os resultados apresentados fornecem uma base sólida para o desenvolvimento de novos produtos funcionais, além de promover a conservação da espécie por meio de sua inclusão em cadeias produtivas sustentáveis.

Diante dos desafios apresentados, é essencial que futuros estudos explorem a variabilidade genética e bioquímica do cambuci, bem como investiguem técnicas que possam melhorar sua produtividade, conservação e preservação. Incentivos à sua comercialização e o desenvolvimento de novos produtos derivados são essenciais para aumentar a demanda e estimular o cultivo, o que contribuiria para a sua propagação.

Há uma necessidade urgente de campanhas de conscientização sobre o valor de frutas nativas, como o cambuci. Ampliar o conhecimento e a valorização dessas frutas é um passo essencial para auxiliar que isto aconteça.