A review of essential oils and their properties in the genus *Campomanesia* (Myrtaceae) from the Brazilian *Cerrado*

Uma revisão de óleos essenciais e suas propriedades no gênero *Campomanesia* (Myrtaceae) do Cerrado Brasileiro

Una revisión de los aceites esenciales y sus propiedades en el género *Campomanesia* (Myrtaceae) del Cerrado Brasileño

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Abstract
The genus *Campomanesia* (Myrtaceae) comprises species with broad economic and scientific interests. They produce essential oils (EO) extracted from leaves, fruits, seeds, roots, and bark. Fourteen *Campomanesia* species are found in the Brazilian *Cerrado*, big Brazilian phytogeographic domain and is a biodiversity and endemic species hotspot. The objective was to understand the genus *Campomanesia* of the Brazilian *Cerrado*, and review species and bioactive constituents in these oils. We searched Scopus, Web of Science, PubMed, Directory of Open Access Journal, and Science Direct with the keywords "essential oil" and "*Campomanesia*" along with the species found in the *Cerrado*. In the resultant 37 publications, we found a variety of potential EO described most of which with antimicrobial and antioxidant activities. *Campomanesia adamantium* and *C. pubescens* were the most often cited species, and five species in the genus were not included by the search criteria. Compounds with potential biological activities include monoterpenes as the main constituents of the volatile oils from fruits, while sesquiterpenes are major compounds in the remaining parts of the plants. Thus, EOs from *Campomanesia* provide potentially interesting and viable alternatives for food and therapeutics. The sustainable use of biodiversity, combined with biotechnology, is the path to develop more natural products or compounds that combine synergistically with synthetic products, reducing the concentrations necessary to achieve the desired effect. Thus, with the many species of *Campomanesia* in the *Cerrado*, conservation of biodiversity can be combined with sustainable use, and provide benefits, from table to pharmacy, into the foreseeable future.
Keywords: Volatile oil; Guavira; Biodiversity; Phytochemicals; Natural products.

Resumo
O gênero *Campomanesia* (Myrtaceae) compreende espécies de interesse econômico e científico. Produzem óleos essenciais (OE), extraídos a partir das folhas, frutos, sementes, raízes e casca. Das espécies de *Campomanesia*, 14 são encontradas no bioma Cerrado, um dos maiores domínios fitogeográficos brasileiros e é *hotspot* de biodiversidade e espécies endêmicas. O objetivo foi compreender os OE do gênero *Campomanesia* do Cerrado brasileiro, revisar as espécies e os constituintes bioativos desses óleos. Foram utilizadas as bases de dados Scopus, Web of Science, PubMed, Directory of Open Access Journal, Science Direct, com as palavras-chave: "essential oil" and "*Campomanesia*" combinada com o nome das espécies do Cerrado. Nas 37 publicações resultantes, há uma variedade de OE potenciais descritos, a maioria dos quais com atividades antimicrobiana e antioxidante. *C. adamantium* e *C. pubescens* foram as mais citadas e cinco espécies no gênero não foram incluídas pelos critérios de pesquisa. Compostos com potencial atividade biológica incluem os monoterpenos como os principais constituintes dos óleos voláteis dos frutos, enquanto os sesquiterpenos são compostos majoritários nas partes restantes das plantas. Assim, os OE da *Campomanesia*

fornecem alternativas potencialmente interessantes e viáveis para alimentação e terapêutica. O uso sustentável da biodiversidade, aliado à biotecnologia, é o caminho para desenvolver produtos mais naturais ou compostos que se combinem sinergicamente com produtos sintéticos, reduzindo as concentrações necessárias para atingir o efeito desejado. Assim, com as muitas espécies de *Campomanesia* no Cerrado, a conservação da biodiversidade pode ser aliada ao uso sustentável e proporcionar benefícios, da mesa à farmácia, em futuro próximo.
Palavras-chave: Óleo volátil; Guavira; Biodiversidade; Compostos fitoquímicos; Produtos naturais.

Resumen
El género *Campomanesia* (Myrtaceae) comprende especies de interés económico y científico. Producen aceites esenciales (AE) extraídos de hojas, frutos, semillas, raíces y corteza. De las especies de *Campomanesia*, 14 están en el Cerrado brasileño, un grande dominio fitogeográfico brasileño y *hotspot* de la biodiversidad y especies endémicas. El objetivo fue comprender los AE del género *Campomanesia* del Cerrado brasileño, revisar las especies y los constituyentes bioactivos de estos aceites. Usamos Scopus, Web of Science, PubMed, Directory of Open Access Journal y Science Direct, con las palabras clave "aceite esencial" y "*Campomanesia*" combinadas con el nombre de las especies del Cerrado. En las 37 publicaciones resultantes, hay una variedad de AE potenciales descritos, la mayoría tenían actividades antimicrobianas y antioxidantes. *C. adamantium* y *C. pubescens* fueron más citadas y cinco especies en el género no se incluyeron en la búsqueda. Los compuestos con actividad biológica potencial incluyen monoterpenos como los principales constituyentes de los aceites de frutas volátiles, mientras que los sesquiterpenos son compuestos principales en las partes restantes. Los AE de *Campomanesia* proporcionan alternativas terapéuticas potencialmente interesantes y viables, además para la alimentación. El uso sostenible de la biodiversidad, combinado con la biotecnología, es la forma de desarrollar productos más naturales o compuestos que se combinen sinérgicamente con productos sintéticos, reduciendo las concentraciones necesarias para lograr el efecto deseado. En fin, con las especies de *Campomanesia* del Cerrado, la conservación de la biodiversidad puede ser aliada al uso sostenible y beneficiarse, de la mesa a la farmacia, en el futuro.
Palabras clave: Aceite volátil; Guavira; Biodiversidad; Compuestos fitoquímicos; Productos naturales.

1. Introduction

Essential oils (EOs) derived from plants can often provide benefits from the use of the native flora rather than manufactured alternatives (Silva et al., 2017; Araújo et al., 2019; Santana et al., 2020; Nascimento et al., 2018;). Many plants in the large and widespread family Myrtaceae are rich in EOs (Alves et al., 2020; Jesus et al., 2020; Santana et al., 2020; Nascimento et al., 2018), which are secondary aromatic volatile metabolites that typically comprise terpenes and hydrocarbons. EOs protect plants against herbivory and microorganisms as well as attract pollinators and seed dispersers (Raven et al., 2007). Human uses of EOs include health benefits due to these bioactive compounds. Scents and flavors of the EOs are of interest to the pharmaceutical, food and cleaning-product industries, along with beauty and aromatherapy applications. EOs derived from the Myrtaceae have been demonstrated to have a variety of biological activities, including antifungal, anti-inflammatory, analgesic, antiproliferative, and antioxidant (Alves et al., 2020; Nascimento et al., 2018; Garcia et al., 2020; Menezes Filho et al., 2020; Sá et al., 2018; Viscardi et al., 2017ab). In *Campomanesia*, EOs extracted from the leaves of *C. sessiliflora* (Jesus et al., 2020), *C. aurea* (Kuhn et al., 2019) and *C. guazumifolia* (Santos et al., 2019) have antibacterial activities, and they can serve as natural preservatives to extend the shelf-life and avoid the proliferation of microorganisms in food products.

Essential oils are volatile and are extracted from plants using a variety of methods (Asbahani et al., 2015; Freitas & Cattelan 2018; Guan et al., 2007). Typical concentrations are low (< 1%, Rao et al., 2019) but in dried plant material have been reported to reach 5% (Asbahani et al., 2015). Extracted EOs are a composite of 20 – 60 components, of which a few (≤ 3) dominate, comprising 20 to 70% of the total (Akthar et al., 2014; Asbahani et al., 2015). The best known and most common terpenes are monoterpenes (with 10 carbon atoms), comprising limonene, α-pinene and β-pinene, and sesquiterpenes (15 carbon atoms), including bicyclogermacrene, spathulenol and thujopsene (Simões & Spitzer, 2000). Biological assays provide evidence that these chemicals have biological activities, such as against cancer (Alves et al., 2020; Garcia et al., 2020; Vasconcelos et al., 2021) and cardiovascular disease (Menezes et al., 2010), along with anti-hyperalgesic and anti-inflammatory activities (Chi et al., 2013; D'Alessio et al., 2013; Piccinelli et al., 2015). Due to these health-related benefits, the global market in EOs is around

US$15 billion, and the price of a kilogram of EO exported from Brazil was US$5.90 in 2021 (Bueno et al., 2021). The EO industry is expanding and finding sources of EOs can be important economically.

Approximately 13% of the world's biodiversity is found within Brazil's borders (Lewinsohn & Prado, 2005; Mittermeier et al., 1997), with the Amazon basin having the majority of this biodiversity and ca. 40% of the remaining tropical forests of the world (Peres, 2005). Next is the *Cerrado*, the savanna biome of Brazil, comprising ca. 21% of the land area of the country, nearly 2 million km^2. About 44% of the flora of the *Cerrado* is endemic and is among the most biodiverse in the world (Klink & Machado, 2005). Despite its biological importance, the Cerrado is quickly losing ground, with ~45% of its original plant cover already lost, and currently has a rate of loss that is 2.5 times that of the Amazon Forest (Projeto Mapbiomas, 2021).

In the Brazilian *Cerrado*, the plant family Myrtaceae comprises 15 genera and 245 species, in which the genus *Campomanesia* accounts for 14 of those species: *C. adamantium* (Cambess.) O.Berg, *C. aurea* O.Berg, *C. cavalcantina* Soares-Silva & Proença, *C. costata* M. Ibrahim & Landrum, *C. eugenioides* (Cambess.) D.Legrand ex Landrum, *C. grandiflora* (Aubl.) Sagot, *C. guaviroba* (DC.) Kiaersk., *C. guazumifolia* (Cambess.) O.Berg, *C. lineatifolia* Ruiz & Pav., *C. pabstiana* Mattos & Legrand, *C. pubescens* (Mart. ex DC.) O.Berg, *C. rufa* (O.Berg) Nied., *C. sessiliflora* (O.Berg) Mattos, and *C. velutina* (Cambess.) O.Berg (Flora do Brasil 2020). Many of these species have long been used for their edible fruits, as ornamentals, as sources of flowers for the production of honey, and for medicinal purposes (Hirschmann, 1988; Macedo et al., 2021; Reis & Schmiele, 2019). Thus, understanding the potential for benefits and applications of the use of natural products from these plants is important for the conservation of this resource and the *Cerrado*. To better understand EOs in the genus *Campomanesia*, here we undertake a review of the genus and the analysis of bioactive products that have been found in these oils in the Brazilian *Cerrado*.

2. Methodology

Using a literature search for all species of *Campomanesia* from the *Cerrado* listed in the Flora of Brazil (2020), we gathered publications that in some way analyzed the essential oils of these plants. This is an integrative literature review, including books, in the search in Scopus, the Web of Science, PubMed, Directory of Open Access Journals, and Science Direct, with attention to more recent publications (from 2000 to 2021). We used the search terms "essential oil" (in Portuguese and English), along with *Campomanesia*, and the 14 species of the *Cerrado*. If publications included the genus, but did not address EOs, chemical and biological characteristics, biodiversity, or bioeconomy, we excluded those sources. Studies of chemical or biological composition of extracts, and not only of the essential oils of the researched species, were also exclusion criteria. Because the references often reported even traces of essential oil components, generating a variable total of often many components, we limit this study to the examination of the three most prevalent components in each reference source.

The integrative review brings a broader analysis of the literature, which contributes to the discussion and validity of methods and results of the studies, besides stimulating future research. This type of review provides a more complete understanding of the topic of interest, as it integrates studies with different methodologies, both experimental and non-experimental, and maintains the methodological rigor of the search, analysis, and synthesis of data (Mendes et al., 2019; Casarin et al., 2020).

3. Results

A total of 37 sources were found in 23 journals that fit our criteria. The two sources with more than one article included the Journal of Essential Oil Research (10 articles) and the Brazilian Journal of Pharmacognosy (four articles), and the number of publications varied by year (Figure 1).

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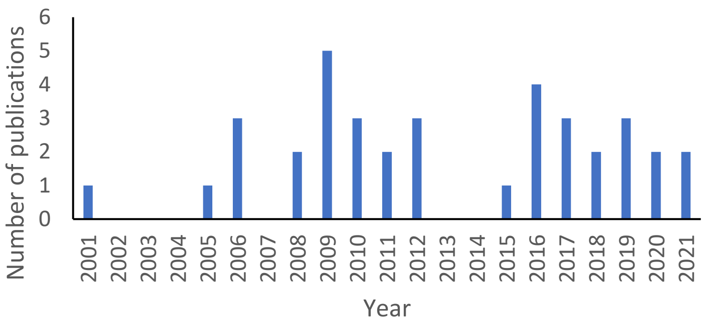
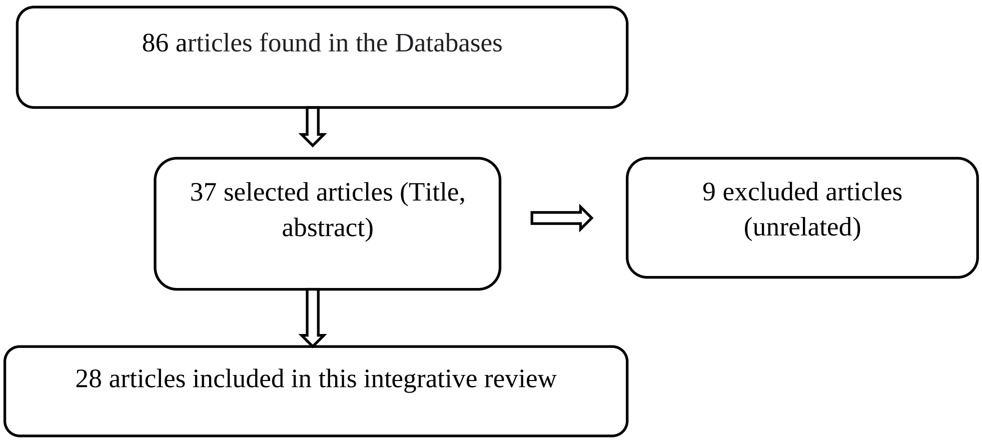
Figure 1 - Distribution of articles indicated by year of publication.



Source: Authors.

Nine articles were subsequently excluded because they were found not to provide useful information about essential oils for our purpose here. In these 28 sources, the species most often cited were *C. adamantium* (24 articles) and *C. pubescens* (8), while *C. cavalcantina*, *C. costata*, *C. grandiflora*, *C. pabstiana*, and *C. rufa* were not reported (Figure 2).

Figure 2 – Research flowchart showing the methods of search and selection of bibliographic sources used in the integrative review.



Source: Authors.

From the research in the databases, the 28 selected articles were analyzed in relation to their content for presentation and discussion in this study (Figure 3).

Figure 3. Characteristics of the studies included in the review of essential oils and their properties in the genus *Campomanesia* (Myrtaceae) from the Brazilian *Cerrado*.

Authors and date	Title	Reason for inclusion in the study and/or topic addressed
Alves et al., 2020	Antiproliferative activity of essential oils from three plants of the Brazilian Cerrado: *Campomanesia adamantium* (Myrtaceae), *Protium ovatum* (Burseraceae) and *Cardiopetalum calophyllum* (Annonaceae)	EO' Chemical characterization Antiproliferative activity Species *C. adamantium*
Cardoso et al., 2009	Fruit Oil of *Campomanesia xanthocarpa* O. Berg and *Campomanesia adamantium* O. Berg	EO' Chemical characterization Species *C. adamantium*
Cardoso & Ré-Poppi, 2009	Identification of the Volatile Compounds of Flower Oil of *Campomanesia pubescens* (Myrtaceae)	EO' Chemical characterization Species *C. pubescens*
Cardoso et al., 2010a	Identification of the Volatile Compounds of Flowers of *Campomanesia sessiliflora* O. Berg and *Campomanesia xanthocarpa* O. Berg	EO' Chemical characterization Species *C. sessiliflora*
Cardoso et al., 2010b	Leaf Oil of *Campomanesia sessiliflora* O. Berg	EO' Chemical characterization Species *C. sessiliflora*
Cardozo et al., 2018	Therapeutic Potential of Brazilian Cerrado *Campomanesia* Species on Metabolic Dysfunctions	Review Species of *Campomanesia*
Chang et al., 2011	Essential Oil Composition and Antioxidant and Antimicrobial Properties of *Campomanesia pubescens* O. Berg, Native of Brazilian Cerrado	EO' Chemical characterization Antimicrobial activity Antioxidant activity Species *C. pubescens*
Coutinho et al., 2009	Gas Chromatography-Mass Spectrometry (GC-MS) and evaluation of antioxidant and antimicrobial activities of essential oil of *Campomanesia adamantium* (Cambess.) O. Berg (Guavira)	EO' Chemical characterization Antimicrobial activity Antioxidant activity Species *C. adamantium*
Coutinho et al., 2008	Identification of the volatile compounds of leaves and flowers in guavira (*Campomanesia adamantium* O. Berg.)	EO' Chemical characterization Species *C. adamantium*
Jesus et al., 2020	Antimicrobial Potential of Essential Oils from Cerrado Plants against Multidrug-Resistant Foodborne Microorganisms	EO' Chemical characterization Antimicrobial activity Species of *Campomanesia*
Kuhn et al., 2019	Antibiofilm activity of the essential oil of *Campomanesia aurea* O. Berg against microorganisms causing food borne diseases	EO' Chemical characterization Antimicrobial, antibiofilm activities Species *C. aurea*
Kuster & Vale, 2016	Leaf histochemistry analysis of four medicinal species from Cerrado	Histochemistry characterization Antimicrobial activity Species *C. adamantium*
Limberger et al., 2001	Aromatic plants from Brazil - Chemical composition of essential oils from some *Campomanesia* species (Myrtaceae)	EO' Chemical characterization Species *C. aurea* Species *C. guazumifolia*
Oliveira et al., 2017	Chemical composition of essential oil extracted from leaves of *Campomanesia adamantium* subjected to different hydrodistillation times	EO' Chemical characterization Species *C. adamantium*
Oliveira et al., 2016	Rendimento, composição química e atividades antimicrobiana e antioxidante do óleo essencial de folhas de *Campomanesia adamantium* submetidas a diferentes métodos de secagem	EO' Chemical characterization Antimicrobial activity Antioxidant activity Species *C. adamantium*
Pacheco et al., 2021	Chemical characterization and antimicrobial activity of *Campomanesia aurea* against three strains of *Listeria monocytogenes*	EO' Chemical characterization Antimicrobial activity Species *C. aurea*

Pascoal et al., 2011	Essential Oil from the Leaves of *Campomanesia guaviroba* (DC.) Kiaersk. (Myrtaceae): Chemical Composition, Antioxidant and Cytotoxic Activity	EO' Chemical characterization Antiproliferative activity Antioxidant activity Species *C. guaviroba*
Sá et al., 2018	Phytochemistry and antimicrobial activity of *Campomanesia adamantium*	EO' Chemical characterization Antimicrobial activity Species *C. adamantium*
Santos et al., 2019	GCxGC/qMS analyses of *Campomanesia guazumifolia* (Cambess.) O. Berg essential oils and their antioxidant and antimicrobial activity	EO' Chemical characterization Antimicrobial activity Antioxidant activity Species *C. guazumifolia*
Silva et al., 2009a	Essential oil composition of the leaves of *Campomanesia pubescens*	EO' Chemical characterization Species *C. pubescens*
Silva et al., 2009b	Fruit Oil of *Campomanesia pubescens* (Myrtaceae)	EO' Chemical characterization Species *C. pubescens*
Stefanello et al., 2008	Essential oil composition of *Campomanesia adamantium* (Camb) O. Berg.	EO' Chemical characterization Species *C. adamantium*
Teixeira et al., 2019	Edible fruits from Brazilian biodiversity: A review on their sensorial characteristics versus bioactivity as tool to select research	Review Several *Campomanesia* species
Vallilo et al., 2006b	Composição química dos frutos de *Campomanesia adamantium* (Cambessédes) O.Berg	EO' Chemical characterization Species *C. adamantium*
Vallilo et al., 2006a	Identificação de terpenos no óleo essencial dos frutos de *Campomanesia adamantium* (Cambessédes) O. Berg – Myrtaceae	EO' Chemical characterization Species *C. adamantium*
Viscardi et al., 2017a	Seed and peel essential oils obtained from *Campomanesia adamantium* fruit inhibit inflammatory and pain parameters in rodents	EO' Chemical characterization Anti-inflammatory, antinociceptive activities Species *C. adamantium*
Viscardi et al., 2017b	Anti-inflammatory, and antinociceptive effects of *Campomanesia adamantium* microencapsulated pulp	Anti-inflammatory, antinociceptive activities Species *C. adamantium*
Yousuf et al., 2021	Incorporating essential oils or compounds derived thereof into edible coatings: effect on quality and shelf life of fresh/fresh-cut produce.	Review of EO Species *C. velutina*

Source: Authors.

Table 1 presents the essential oil components of the *Campomanesia* species researched and the parts of the plant from which the EO was extracted. Plant parts used for extraction of the essential oils, when and where they were collected, were quite variable. Consequently, yields were variable, sometimes for the same species and plant parts. Also, the units of measurement varied and were either weight by weight, or volume by weight and the parts may have been dried or not. Some examples include the leaves of *C. adamantium*, the most often studied species, in which monoterpenes accounted for 27%, sesquiterpenes for 68%, and other hydrocarbons (5%) of the EO components identified (Sá et al., 2018). Limonene (13% in fruit skins, 21% in seeds), thujopsene (7% in the fruit skin), and β-pinene (11% in seeds) were also found (Viscardi et al., 2017a). Sesquiterpenes predominate in extraction from fresh flowers (Coutinho et al., 2008) while monoterpenes are more common in dried flowers (Sá et al., 2018). EO components in *C. pubescens* tended to include bicyclogermacrene, germacrene-D and eucalyptol (Chang et al., 2011). Also, in that species, at different phases in the phenology, other EO products found included spathulenol, caryophyllene oxide, and α-macrocarpene (Costa et al., 2021). Bicyclogermacrene (sesquiterpene) was also prevalent (15%) in *C. guazumifolia* (Santos et al. 2019).

Table 1. Essential oil components, source species, and plant parts, in which they were found, range of relative yield, and references for *Campomanesia* spp. cited in this review, in the Brazilian *Cerrado*.

Component[1]	Species[2]	Part	Yield (%)	Reference[3]
		Monoterpene		
Limonene	a., p.	flower, fruit, leaf, seed	10 - 26	3, 11, 14, 15
Sabinene	a.	flower	20	11
Verbenene	a.	leaf	14	11
α-pinene	a., p.	fruit, seed	8 - 11	14, 15
α-thujene	a.	flower	9	11
(Z)-β-ocimene	a.	fruit	9	14
β-pinene	a.	seed	11	15
Eucalyptol	p.	fruit, leaf	8 - 25	3
Myrtenal	g.	leaf	27	10
Myrtenol	g.	leaf	25	10
Trans-pinocarveol	g.	leaf	16	10
Terpinolene	au.	leaf	4 - 10	7, 9
Linalool	au.	leaf	6 - 9	7, 9
Geraniol	a.	leaf	18	13
		Sesquiterpene		
Globulol	a., p., s., gu.	flower, fruit, leaf	5 - 9	1, 5, 6, 12, 13
Spathulenol	a., p., s., gu.	fruit, leaf	1 - 43	2, 4, 6, 8, 12, 13
Ledol	a., p., s.	flower	19 - 21	1, 5, 12
Bicyclogermacrene	a., p., s., gu.	Leaf, fruit	5 - 22	3, 4, 6, 15
Cryptomeridiol	p.	fruit	14	12
Thujopsene	a.	fruit	7	15
α-cadinol	a., au., p., s.	flower, leaf	7 - 13	1, 5, 9, 12
α-macrocarpene	p.	leaf	2 - 22	4
β-funebrene	a.	leaf	12	11
Germacrene-B	a.	leaf	9 - 27	8
Germacrene-D	p., s.	leaf	8 - 15	2, 3
(E)-Nerolidol	au.	leaf	56	7
Caryophyllene oxide	a., p.	leaf	1 - 30	4, 8

[1]Three most prevalent components in the studies.
[2]Species codes: a. - *C. adamantium*, au. - *C. aurea*, g. - *C. guaviroba*, gu. - *C. guazumifolia*, p. - *C. pubescens*, s. - *C. sessiliflora*.
[3]Reference: 1 - Cardoso et al., (2010a), 2 - Cardoso et al., (2010b), 3 - Chang et al., (2011), 4 – Da Costa et al., (2021), 5 - Coutinho et al., (2008), 6 - Santos et al., (2019), 7 - Kuhn et al., (2019), 8 - Oliveira et al., (2016), 9 - Pacheco et al., (2021), 10 - Pascoal et al., (2011), 11 - Sá et al., (2018), 12 - Silva et al., (2009b), 13 - Stefanello et al., (2008), 14 - Vallilo et al., (2006a,b), 15 - Viscardi et al., (2017a). Source: Authors.

Most studies (25 articles) included chemical analyses of the composition of essential oil (Table 1), and some studies examined therapeutic effects and possible applications for the EOs, especially of those species found in the Cerrado. In those few, antimicrobial (11 articles) and antioxidant (eight articles) were the most cited uses (Table 2). Only three articles were found that reviewed uses, including ethnobotanical and pharmacological, of *Campomanesia* in the Cerrado.

Table 2. List of species in the genus *Campomanesia*, the plant part from which it was extracted, and the potential biological applications of their essential oils as stated in the study, studied in the *Cerrado* of Brazil.

Source species	Part	Biological application	Reference[1]
C. adamantium	fruit, seed	inflammation, nociception	10
	leaf, flower	antimicrobial	9
	leaf	antioxidant	2
	leaf	antiproliferative	1
C. aurea	leaf	neoplasm, antibacterial	6, 7
C. guaviroba	leaf	leukemia	8
C. guazumifolia	leaf	antioxidant, antibacterial	5
C. pubescens	leaf, fruit, stem, root	antibacterial	3
C. sessiliflora	leaf	antibacterial	4

[1]Reference: 1 - Alves et al., (2020), 2 - Coutinho et al., (2009), 3 - Chang et al., (2011), 4 - Jesus et al., (2020), 5 - Santos et al., (2019), 6 - Garcia (2020), 7 - Pacheco et al., (2021), 8 - Pascoal et al., (2011), 9 - Sá et al., (2018), 10 - Viscardi et al., (2017a). Source: Authors.

4. Discussion

Campomanesia has both common (within the genus), and species-specific, characteristics of compounds, nutritional properties, and biological potential. Phenolic compounds are most widespread in the form of anthocyanins, chalconoids, coumarins, and tannins. Fruits are the most commonly used for extractions, yet leaves, flowers, seeds and roots are all used for food and medicinal purposes (Cardoso 2021; Duarte et al., 2020). *Campomanesia adamantium* was the most frequently studied species which seems to reflect interest, or perhaps local abundance.

The fruit of the *guavira* (*Campomanesia* spp.) in 2017 was declared to be the fruit symbol of the state of Mato Grosso do Sul, which reflects the regional importance given to these species. Consequently, research and integration with communities and agrobusinesses have addressed preservation, sustainable use, product development, and improvements in the production and supply chain (Cardoso, 2021). Fruits tend to be flavorful, sweet, with ample pulp, and an agreeable aroma (Teixeira et al., 2019), and are eaten fresh, or in ice creams, juices, jellies and liquors. Studies suggest that there are many benefits associated with the fruit, including the pulp, which when reconstituted, after being dried, in juices retains high quantities of vitamin C (Breda et al., 2012; Oliveira et al., 2018). Vitamin C in the pulp can reach 279 mg $100g^{-1}$ (Breda et al., 2012; Oliveira et al., 2018; Leão et al., 2017). Minerals are also in relatively high concentrations (Lima et al., 2016), as are phenolic compounds (Alves et al., 2017; Duarte et al., 2020) and fiber (Alves et al., 2013). Even the seeds are used in the production of vegetable oils, with yields around 80%. The most common oils tend to be palmitic (53%) and oleic (34%) acids (Machate et al., 2020).

Many potentially important food and therapeutic uses of this group of plants are indicated by the nutritional, mineral, and bioactive compounds found therein (Alves et al., 2013, 2017; Lescano et al., 2018, 2019; Lima et al., 2016; Souza et al., 2019). We suggest that additional and standardized scientific studies should examine more species in the genus and examine ways to develop and use their products. Clearly, the genus contains many primary metabolites that provide nutrients, along with secondary metabolites (phenols and essential oils) that may have important biological activities and healthcare uses. Thus, developing this source of products that can be used from food, to cosmetics and pharmacology, may also be the means by which sustainable use of the plants involved can offer protection for the Brazilian *Cerrado*.

Products that are obtained from natural sources in the *Cerrado*, such as the infusions (Catelan et al., 2018), essential oils (Jesus et al., 2020; Viscardi et al., 2017a) and extracts (Fernandes et al., 2015; Lescano et al., 2018) can often be natural alternatives for therapeutics, in addition to food that the fruits provide. While some of these uses already figure largely in the local pharmacological folklore, developing standardized formulations and applications is a challenge, because of the chemical complexity, instability, and possible toxicity (Armendáriz-Barragán et al., 2016; Lima et al., 2016) that must be resolved to bring these items to market.

Bioactive compounds tend to be chemically unstable due to light, oxygen, humidity and heat, which can cause undesirable consequences for the activity or flavor of the products to which they are added. Additionally, solubility and bioavailability also limit their use in foodstuffs or pharmacological applications, and which may also influence their attractiveness to the consumer (Ariyarathna & Karunaratne, 2016; Shishir et al., 2018). Thus, surmounting these difficulties will be required to bring these products to market in a useful, beneficent and stable way.

4.1 Chemistry of *Campomanesia* essential oils

Plants in the Myrtaceae have secretory cavities that produce lipophilic compounds (Santana et al., 2020; Hanif et al., 2018; Siddique et al., 2020). For example, in *C. adamantium* the idioblasts were shown to produce the essential oils (Kuster & Vale, 2016). But, other parts of the plants, those that are typically discarded (skins, seeds) may also contain EOs and so, if extraction methods can prove cost-effective, can add value to the use of these plants for these products (Alves et al., 2013; Lescano et al., 2018; Medino et al., 2019; Schneider et al., 2020; Viscardi et al., 2017a) (Table 1).

Various parts of the plants do indeed have EOs and components which seem to vary by species, as well as in the same species. For example, in the leaves of *C. pubescens* bicyclogermacrene, germacrene-D and eucalyptol (Chang et al., 2011), or spathulenol, caryophyllene-oxide, and α-macrocarpene (Costa et al., 2021), or limonene, α-pinene, and sabinene were dominant (Silva et al., 2009a). Also, in this species, when examining the effects of phenology, spathulenol, caryophyllene oxide, α-macrocarpene and z-caryophyllene were also dominant at times (Costa et al., 2021). Bicyclogermacrene (15%, a sesquiterpene) was dominant in extractions from leaves of *C. guazumifolia* (Santos et al., 2019), while caryophyllene oxide (29%) and spathulenol (28%, both sesquiterpenes) were predominant in *C. aurea* and *C. guazumifolia* (Limberger et al., 2001). In *C. adamantium*, caryophyllene-oxide and spathulenol are dominant (Oliveira et al., 2016). The variable nature of all of these constituents both among species, plant parts and studies are complex. The lack of standardization in all of these areas is likely to be responsible for some of this variability, and thus a first step in making these products commercially available would be to resolve that issue. First, controlled studies should examine few plants of selected species and over time, to discover when, and in which plant part, EO concentrations are at their peak.

This variability is demonstrated in *Campomanesia* where fruits tend to yield monoterpenes while flowers and leaves yield sesquiterpenes, and both specific mono- and sesquiterpenes can vary by species and part. The monoterpenes are the source of the citric aroma of the fruits (Vallilo et al., 2006b). Also, occasionally sesquiterpenes can be more dominant than monoterpenes in fruits (Cardoso et al., 2009; Silva et al., 2009b). Seeds (1%) and fruit skins (0.5%) usually contain smaller quantities of EOs than leaves which are easier to work with. However, in some cases, leaves have similar, low, yields (0.016 – 0.4%) (Santos et al., 2019; Pascoal et al., 2011; Stefanello et al., 2008), yet limonene, often the dominant EO, can yield 13 – 21% (Viscardi et al., 2017a). To add to the complexity, while most studies used dried materials for extraction, drying the material, and the extraction methods themselves as they were used, may not be important (Silva et al., 2019a; Silva et al., 2013). We reiterate the need for standardizing all steps in the process of extracting EOs.

Typically, extraction of EO and other organic chemicals is carried out through hydrodistillation or steam distillation, and so methods are similar across studies. The duration of time the plant parts are exposed to the procedure can vary among studies, but nonetheless, evidence suggests that yield is fairly constant at economically viable values (Table 1). For example, with leaves from *C. adamantium*, yield after two hours of extraction (0.3% w/w) was similar to that after 2 – 5 hours, but at longer time intervals, more compounds were extracted (Oliveira et al., 2017). In contrast, with dried leaves of *C. adamantium*, the yield after four hours 0.5% v/w (Oliveira et al., 2016) was half that after two hours in another study (1%, Sá et al., 2018). Extraction can be with wet or dry material, and the difference between yield of EOs of the two methods was around higher 15% using dry leaves of Myrtaceae (Silva et al., 2019b). Also, yield and composition of the EO can be influenced by a variety of factors, including climate, soil type, genetics, species of interest, timing of harvest, phenology (Coutinho et al., 2009; Sá et al., 2018), and plant part (Sá et al., 2018).

4.2. Potential uses of the Essential Oils

4.2.1 Antimicrobial

Essential oils comprise terpenes, terpenoids, phenylpropenes and other constituents that are antimicrobial agents (Hyldgaard et al., 2012). EOs extracted from *C. guazumifolia* leaves had effects on *Staphylococus aureus*, *Escherichia coli*, and *Candida albicans* (Santos et al., 2019), while leaves and flowers of *C. adamantium* were active against *Trichophyton mentagrophytes* (Sá et al., 2018). EOs from *C. pubescens* (all plant parts) were effective against both aerobic and anaerobic bacteria, and were recommended to be used as a mouthwash (Chang et al., 2011). EOs from *C. sessiliflora* were active against *Salmonella Typhi* 905, which is antibiotic resistant (to clindamycin, penicillin and oxacillin (MIC = 500 $\mu g \cdot mL^{-1}$). The primary component of those oils was α-pinene (39%), a monoterpene already approved by the USA Food and Drug Administration (FDA) as a food additive (Jesus et al., 2020).

The mechanism of antimicrobial action of these EOs is typically through disruption of the cell membrane, in which permeability changes causing problems with cellular respiration, cytoplasm coagulation, protein denaturation, and enzyme deactivation (Akthar et al., 2014; Khorshidian et al., 2018). Lipophilic components of the EOs (terpenes) interact with the lipids of the cell membranes, thereby causing the antibacterial effects (Oliveira et al., 2016). Because this damage is mechanical, resistance (as with antibiotics) does not occur, and so these EOs may be useful in situations in which antibiotic resistance is a problem, such as in hospitals (Mourabit et al., 2020).

4.2.2 Anti-inflammatory, antinociceptive

Essential oils from the skins and seeds of *C. adamantium* had anti-inflammatory and antinociceptive actions in rodents, without apparent toxicity (Viscardi et al., 2017a). The anti-inflammatory action of the EOs from seeds was due to the inhibition of leukocyte migration and edema.

4.2.3 Tumor prevention

Myrtenal and myrtenol, extracted from the leaves of *C. guaviroba*, were demonstrated to have cytotoxicity (IC_{50} = 19.31 $\mu g \cdot mL^{-1}$) with several lineages of human leukemia cells (Pascoal et al., 2011). Spathulenol, germacrene-B, β-caryophyllene, β-caryophyllene oxide, β-myrcene, and α-pinene (only the latter two are not sesquiterpenes) from the leaves of *C. adamantium* had antiproliferative effects against human tumor (GM07492A, pulmonary fibroblasts) cells (Alves et al., 2020). Spathulenol, typically a dominant constituent of EOs in the leaves of *C. adamantium* (Oliveira et al., 2016) and *Psidium guineense* (81%) was effective against a tumor causing cell lineage (MCF-7) (Nascimento et al., 2018). Essential oils from *C. aurea* reduced cellular viability and the ability to form colonies in human cervical cancer cells (SiHa), possibly due to the important sesquiterpene constituent α-cadinol (11%). That constituent was demonstrated to inhibit viability by 97%, with and $IC_{50} \leq 0.045$ µg·mL^{-1} which was shown to essentially only affect tumor cells, leaving healthy cells intact (Garcia et al., 2020). Finally, antimutagenic and anticarcinogenic effects may be due, in part, to the antioxidant properties that attack free radicals (Freitas & Cattelan, 2018).

4.2.4 Antioxidant properties

Secondary metabolism is responsible for the production of compounds, including antioxidants, with biological activities in plants (Duarte et al., 2020). Antioxidant activity is attributed to the hydroxyl group in phenols in essential oils. Phenols are oxygen reducers and can act as chelating agents and to eliminate free radicals (Freitas & Cattelan, 2018). While antioxidant activity is often attributed to the primary constituents of EOs, such activity may also be synergistic among the components of EOs (Andrade et al., 2012, Marin et al., 2008). Antioxidants work by transferring a hydrogen atom (HAT) or an electron (SET) and by chelating transition metals; these methods are used to quantify antioxidant activity (Santos-Sánchez et al., 2019). To evaluate EOs, typical methods use the radical 2,2-diphenyl-1-picrylhydrazyl (DPPH), the radical 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), ferric reducing antioxidant power (FRAP), inhibition of peroxidation using the β-carotene/linoleic acid method, and the oxygen radical absorbance capacity (ORAC) (Alves et al., 2017; Schneider et al., 2020).

Essential oils from *C. guazumifolia* leaves inhibited by 50% the free radical DPPH ($IC_{50} = 26.06$ µg·mL^{-1}), like the synthetic antioxidant butyl-hydroxytoluene (BHT, $IC_{50} = 18$ µg·mL^{-1}) and $IC_{50} = 68$ µg·mL^{-1} through the inhibition of whitening of β-carotene, similar to the quercetin control ($IC_{50} = 80$ µg·mL^{-1}). Greater activity of the β-carotene method was attributed to lipophilic antioxidant compounds in the EOs (Santos et al., 2019). Low antioxidant activity using the DPPH method may be due to use with hydrophilic compounds (Andrade et al., 2012). Essential oils from the leaves of *C. adamantium* and *C. guaviroba* may have low antioxidant capacities due to the DPPH method (Coutinho et al., 2009; Oliveira et al., 2016; Pascoal et al., 2011).

4.2.5 Foods

Essential oils in foods can maintain or improve colors and flavors of the food, increase shelf life, and substitute synthetic antioxidants or antimicrobials. To date, despite the analyses of EOs in *Campomanesia*, studies that examine their application are few. Nonetheless, EOs from leaves of *C. adamantium* inhibit growth (MIC = 31.25 µg·mL^{-1}) of the bacteria *Listeria monocytogenes* (Sá et al., 2018) and from the leaves of *C. aurea* inhibit biofilms (> 90%, at 4 mg·mL^{-1}) of *L. monocytogenes* and *Staphylococcus aureus*, and these bacteria are often associated with food-related illnesses (Kuhn et al., 2019, Pacheco et al., 2021). Also, leaves of *C. sessiliflora* have EOs with antibacterial properties (MIC = 31.25 µg·mL^{-1}) for *S. aureus*, which produces enterotoxins and can cause alimentary tract infections (Jesus et al., 2020). Studies of other species in the Myrtaceae (e.g., *Melaleuca*) also have antioxidant along with bactericidal activities against *S. aureus* and may also provide a potential source of food preservatives (Siddique et al., 2020).

Antimicrobial activities, along with agreeable scents, have been cited in a variety of studies (Silva et al., 2018; Freitas & Cattelan, 2018; Rao et al., 2019). Flower buds in clove (*Syzygium aromaticum*, also Myrtaceae) inhibit and kill bacteria (*Staphylococcus aureus*, *Escherichia coli*, *Listeria monocytogenes* and *Salmonella typhimurium*) and can be added to foods as a preservative (Hassine et al., 2021; Radünz et al., 2019).

Essential oil compounds (sesquiterpenes and monoterpenes) combined with moderate heat (54°C) or pulses of electricity, can have even better antimicrobial properties against gram-positive bacteria, such as *Listeria monocytogenes* and gram-negative bacteria such as *E. coli*. These combinations may allow the use of smaller quantities of the EOs to conserve foods.

These methods have been shown to be effective with extracts of other species, such as *Citrus sinensis* (Ait-Ouazzou et al., 2011; Bento et al., 2020), in which limonene is the primary component (Bento et al., 2020), and is also common in *Campomanesia* (Chang et al., 2011; Sá et al., 2018; Viscardi et al., 2017a).

5. Final Considerations

Essential oils and their constituents are ubiquitous in the genus *Campomanesia*. Here, in this review we provide ample evidence for many uses of those EOs as therapeutics with a variety of applications and addition to food products to increase shelf life. The abundance of species of *Campomanesia* in the *Cerrado* of Brazil supports our suggestion that this region can become an important source of these products. Conversely, by using plants in this genus, we may develop a more sustainable and natural way to develop health-related products as we conserve the *Cerrado*. Additionally, better understanding of the species and their associated EO, their phenologies and how they interact with the production of these compounds, can provide a new and safer source of therapeutic products that can replace the more commonly used synthetics. As food additives, these natural products might be more harmless and more agreeable to consumers because they are natural. Also, because these products are collected from live plants, as leaves, flowers and fruits, they are a renewable resource.

While the *Campomanesia* spp. is somewhat well-known, the many species and their products are not. Many species of the *Cerrado*, including *C. cavalcantina*, *C. costata*, *C. grandiflora*, *C. pabstiana and C. rufa* have received almost no attention. The focus of study is *C. adamantium* in the vast majority of studies. Yet even this species has lacunae with respect to the potential essential oil components it produces. Clearly with the species diversity in the *Cerrado,* chemical analysis of all of these species should be carried out. All parts of the plants may have EOs that are useful, and so even after fruit collection for food, leftover products, including fruit skins and seeds, can also be used for the extraction of potentially useful EOs.

Brazil, due to a combination of factors, including size, geography, topography, and evolution, has extreme biodiversity. With our review, we suggest that conservation of the *Cerrado* can, in part, include development of the use of the many species in the genus *Campomanesia*, from fruit on the table to medicines in the hospital.

Thus, these plants, and their EO products, should continue to be studied. Research programs should include an examination of the phenology and parts of the plants with respect to concentrations of the EOs. Next, better, experimental, and standardized studies of the EOs components and their potential uses should receive more interest. Furthermore, the potential for cancer inhibition of the analyzed species has extreme importance and should receive more attention in research.

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References

Ait-ouazzou, A., Cherrat, L., Espina, L., Lorán, S., Rota, C., & Pagán, R. (2011). The antimicrobial activity of hydrophobic essential oil constituents acting alone or in combined processes of food preservation. Innov. *Food Sci. Emerg. Technol*. 12(3):320–329. https://doi.org/10.1016/j.ifset.2011.04.004

Akthar, M., Degaga, B., & Azam, T. (2014). Antimicrobial activity of essential oils extracted from medicinal plants against the pathogenic microorganisms: a review. *Issues Biol. Sci. Pharm. Res*. 2(1):1–7.

Alves, A.M., Alves, M.S.O., Fernandes, T. de O., Naves, R.V., & Naves, M.M.V. (2013). Caracterização física e química, fenólicos totais e atividade antioxidante da polpa e resíduo de gabiroba. *Rev. Bras. Frutic*. 35(3):837–844. https://doi.org/10.1590/S0100-29452013000300021

Alves, A.M., Dias, T., Hassimotto, N.M.A., & Naves, M.M.V. (2017). Ascorbic acid and phenolic contents, antioxidant capacity and flavonoids composition of Brazilian savannah native fruits. *Food Sci. Technol.* 37(4):564–569. https://doi.org/10.1590/1678-457X.26716

Alves, C.C.F., Oliveira, J.D., Estevam, E.B.B., Xavier, M.N., Nicolella, H.D., Furtado, R.A., Tavares, D.C., & Miranda, M.L.D. (2020). Antiproliferative activity of essential oils from three plants of the Brazilian Cerrado: *Campomanesia adamantium* (Myrtaceae), *Protium ovatum* (Burseraceae) and *Cardiopetalum calophyllum* (Annonaceae). *Braz. J. Biol*. 80(2):290–294. https://doi.org/10.1590/1519-6984.192643

Andrade, M.A., Cardoso, M. das G., Batista, L.R., Mallet, A.C.T., & Machado, S.M.F. (2012). Essential oils of *Cinnamomum zeylanicum*, *Cymbopogon nardus* and *Zingiber officinale*: Composition, antioxidant and antibacterial activities. *Rev. Ciência Agronômica* 43(2):399–408. https://doi.org/10.1590/S1806-66902012000200025

Araújo, F.F. de, Neri-Numa, I.A., Paulo Farias, D. de, Cunha, G.R.M.C. da, & Pastore, G.M. (2019). Wild Brazilian species of *Eugenia* genera (Myrtaceae) as an innovation hotspot for food and pharmacological purposes. *Food Res. Int*. 121:57–72. https://doi.org/10.1016/j.foodres.2019.03.018

Ariyarathna, I.R., & Karunaratne, D.N. (2016). Microencapsulation stabilizes curcumin for efficient delivery in food applications. *Food Packag. Shelf Life* 10:79–86. http://dx.doi.org/10.1016/j.fpsl.2016.10.005

Armendáriz-Barragán, B., Zafar, N., Badri, W., Galindo-Rodríguez, S.A., Kabbaj, D., Fessi, H., & Elaissari, A. (2016). Plant extracts: from encapsulation to application. *Expert Opin. Drug Deliv*. 13(8):1165–1175. http://dx.doi.org/10.1080/17425247.2016.1182487

Asbahani, A. El, Miladi, K., Badri, W., Sala, M., Addi, E.H.A., Casabianca, H., Mousadik, A. El, Hartmann, D., Jilale, A., Renaud, F.N.R., & Elaissari, A. (2015). Essential oils: From extraction to encapsulation. *Int. J. Pharm*. 483(1–2):220–243. https://doi.org/10.1016/j.ijpharm.2014.12.069

Bento, R., Pagán, E., Berdejo, D., Carvalho, R.J. de, García-Embid, S., Maggi, F., Magnani, M., De Souza, E.L., García-Gonzalo, D., & Pagán, R. (2020). Chitosan nanoemulsions of cold-pressed orange essential oil to preserve fruit juices. *Int. J. Food Microbiol*. 331:108786. https://doi.org/10.1016/j.ijfoodmicro.2020.108786

Breda, C.A., Sanjinez-Argandoña, E.J., & Correia, C.D.A.C. (2012). Shelf life of powdered *Campomanesia adamantium* pulp in controlled environments. *Food Chem*. 135(4):2960–2964. http://dx.doi.org/10.1016/j.foodchem.2012.07.029

Cardoso, C.A.L. (2021). *Plantas do gênero Campomanesia*: potencial medicinal e nutracêutico. UEMS, Dourados.

Cardoso, C.A.L., & Ré-Poppi, N. (2009). Identification of the Volatile Compounds of Flower Oil of *Campomanesia pubescens* (Myrtaceae). *J. Essent. Oil Res*. 21(5):433-434. DOI:10.1080/10412905.2009.9700210

Cardoso, C.A.L., Lima, A.S.V., Ré-Poppi, N., & Vieira, M.D.C. (2009). Fruit oil of *Campomanesia xanthocarpa* O. Berg and *Campomanesia adamantium* O. Berg. *J. Essent. Oil Res*. 21(6):481–483. https://doi.org/10.1080/10412905.2009.9700223

Cardoso, C.L., Kataoka, V.M.F., & Ré-Poppi, N. (2010a). Identifcation of the volatile compounds of flowers of *Campomanesia sessilifora* O. Berg and *Campomanesia xanthocarpa* O. Berg. *J. Essent. Oil Res*. 22(3):254–256. http://dx.doi.org/10.1080/10412905.2010.9700318

Cardoso, C.L., Kataoka, V.M.F., & Ré-Poppi, N. (2010b). Leaf oil of *Campomanesia sessiliflora* O. Berg. *J. Essent. Oil Res*. 22(4):303–304. https://doi.org/10.1080/10412905.2010.9700330

Casarin, S.T., Porto, A.R., Gabatz, R.I.B., Bonow, C.A., Ribeiro, J.P., Mota, M.S. Tipos de revisão de literatura: considerações das editoras do Journal of Nursing and Health. *Journal of Nursing and Health*. 10(5):e20104031. https://periodicos.ufpel.edu.br/ojs2/index.php/enfermagem/article/view/19924

Catelan, T.B.S., Santos Radai, J.A., Leitão, M.M., Branquinho, L.S., Vasconcelos, P.C. De P., Heredia-Vieira, S.C., Kassuya, C.A.L., & Cardoso, C.A.L. (2018). Evaluation of the toxicity and anti-inflammatory activities of the infusion of leaves of *Campomanesia guazumifolia* (Cambess.) O. Berg. *J. Ethnopharmacol*. 226(June):132–142. https://doi.org/10.1016/j.jep.2018.08.015

Chang, R., De Morais, S.A.L., Nascimento, E.A. do, Cunha, L.C.S., Rocha, E. De O., De Aquino, F.J.T., De Souza, M.G.M., Cunha, W.R., & Martins, C.H.G. (2011). Essential oil composition and antioxidant and antimicrobial properties of *Campomanesia pubescens* O. Berg, native of Brazilian Cerrado. *Lat. Am. J. Pharm*. 30(9):1843–1848.

Chi, G., Wei, M., Xie, X., Soromou, L.W., Liu, F., & Zhao, S. (2013). Suppression of MAPK and NF-κB pathways by limonene contributes to attenuation of lipopolysaccharide-induced inflammatory responses in acute lung injury. *Inflammation* 36(2):501–511. https://doi.org/10.1007/s10753-012-9571-1

Costa, H.M. da, Fiuza, T. de S., Ferreira, H.D., Abrao, F.Y., Romano, C.A., Borges, L.L., & Paula, J.R. de. (2021). Morphoanatomical study, seasonal variation, and larvicidal activity of volatile oils from the leaves of *Campomanesia pubescens* (DC.) O. Berg (Myrtaceae). *Res. Soc. Dev*. 10(3):e35610313412. https://doi.org/10.33448/rsd-v10i3.13412

Coutinho, I.D., Cardoso, C.A.L., Ré-Poppi, N., Melo, A.M., Vieira, M.D.C., Honda, N.K., & Coelho, R.G. (2009). Gas Chromatography-Mass Spectrometry (GC-MS) and evaluation of antioxidant and antimicrobial activities of essential oil of *Campomanesia adamantium* (Cambess.) O. Berg (Guavira). *Brazilian J. Pharm. Sci.* 45(4):767–776. https://doi.org/10.1590/S1984-82502009000400022

Coutinho, I.D., Poppi, N.R., & Cardoso, C.L. (2008). Identification of the volatile compounds of leaves and flowers in Guavira (*Campomanesia adamantium* O. Berg.). *J. Essent. Oil Res*. 20(5):405–407. http://dx.doi.org/10.1080/10412905.2008.9700041

D'alessio, P.A., Ostan, R., Bisson, J.F., Schulzke, J.D., Ursini, M. V., & Béné, M.C. (2013). Oral administration of d-Limonene controls inflammation in rat colitis and displays anti-inflammatory properties as diet supplementation in humans. *Life Sci.* 92(24–26):1151–1156. https://doi.org/10.1016/j.lfs.2013.04.013

Duarte, L.D.S., Pereira, M.T.M., Pascoal, V.D.B., & Pascoal, A.C.R.F. (2020). *Campomanesia* genus – a literature review of nonvolatile secondary metabolites, phytochemistry, popular use, biological activities, and toxicology. *Eclética Química J*. 45(2):12-22. DOI: 10.26850/1678-4618eqj.

Fernandes, T. de O., Ávila, R.I. de, Moura, S.S. de, Ribeiro, G. de A., Naves, M.M.V., & Valadares, M.C. (2015). *Campomanesia adamantium* (Myrtaceae) fruits protect HEPG2 cells against carbon tetrachloride-induced toxicity. *Toxicol. Reports* (2):184–193. https://doi.org/10.1016/j.toxrep.2014.11.018

Flora do Brasil. (2020). Jardim Botânico do Rio de Janeiro. Disponível em: http://floradobrasil.jbrj.gov.br/.
Freitas, I.R., & Cattelan, M.G. (2018). Chapter 15 - Antimicrobial and Antioxidant Properties of Essential Oils in Food Systems— An Overview. Microbial

Contamination and Food Degradation. Handbook of Food Bioengineering. 443 - 470.

Garcia; H.O., Pacheco, L.A., Nuñez, J.G., Pinto, G.C., La Porta, V.G., Padilha, G.L., Ethur, E.M., Hoehne, L,.& Bruno, A.N. (2020). Essential oil of *Campomanesia aureas*: chemical composition and anti-neoplastic potential in-vitro. *Int. J. Pharmacogn*. 7(12):361–368.

Guan, W., Li, S., Yan, R., Tang, S., & Quan, C. (2007). Comparison of essential oils of clove buds extracted with supercritical carbon dioxide and other three traditional extraction methods. *Food Chem*. 101(4):1558–1564. https://doi.org/10.1016/j.foodchem.2006.04.009

Hanif, M.U., Hussain, A.I., Chatha, S.A.S., Kamal, G.M., & Ahmad, T. (2018). Variation in Composition and Bioactivities of Essential Oil from Leaves of Two Different Cultivars of *Psidium guajava* L. *J. Essent. Oil-Bearing Plants* 21(1):65–76. https://doi.org/10.1080/0972060X.2018.1431152

Hassine, D.B., Kammoun El Euch, S., Rahmani, R., Ghazouani, N., Kane, R., Abderrabba, M., & Bouajila, J. (2021). Clove Buds Essential Oil: The Impact of Grinding on the Chemical Composition and Its Biological Activities Involved in Consumer's Health Security. *Biomed Res. Int*. 940591:1–11. https://doi.org/10.1155/2021/9940591

Hirschmann, G.S. (1988). Ethnobotanical observations on paraguayan Myrtaceae. I. *J. Ethnopharmacol*., 22(1), 73-79. https://doi.org/10.1016/0378-8741(88)90232-2

Hyldgaard, M., Mygind, T., & Meyer, R.L. (2012). Essential oils in food preservation: Mode of action, synergies, and interactions with food matrix components. *Front. Microbiol*. 3(12):1–24. https://doi.org/10.3389/fmicb.2012.00012

Jesus, G.S., Micheletti, A.C., Padilha, R.G., Souza de Paula, J. de, Alves, F.M., Leal, C.R.B., Garcez, F.R., Garcez, W.S., & Yoshida, N.C. (2020). Antimicrobial potential of essential oils from cerrado plants against multidrug-resistant foodborne microorganisms. *Molecules* 25(14):1–10. https://doi.org/10.3390/molecules25143296

Khorshidian, N., Yousefi, M., Khanniri, E,. & Mortazavian, A.M. (2018). Potential application of essential oils as antimicrobial preservatives in cheese. *Innov. Food Sci. Emerg. Technol*. 45:62–72. https://doi.org/10.1016/j.ifset.2017.09.020

Klink, C.A., & Machado, R.B. (2005). Conservation of the Brazilian Cerrado. *Conserv. Biol*. 19(3):707–713.

Kuhn, D., Ziem, R., Scheibel, T., Buhl, B., Vettorello, G., Pacheco, L.A., Heidrich, D., Kauffmann, C., De Freitas, E.M., Ethur, E.M., & Hoehne, L. (2019). Antibiofilm activity of the essential oil of *Campomanesia aurea* O. Berg against microorganisms causing food borne diseases. *Food Sci. Technol*. 108:247–252. https://doi.org/10.1016/j.lwt.2019.03.079

Kuster, V.C., & Vale, F.H.A. (2016). Leaf histochemistry analysis of four medicinal species from Cerrado. *Brazilian J. Pharmacogn*. 26(6):673 - 678. https://doi.org/10.1016/j.bjp.2016.05.015

Leão, M.M., Dellaqua, G.F., Ferreira, M.D., Hubinger, S.Z., Marques, M.O.M., & Spoto, M.H.F. (2017). The Potencial of *Campomanesia phaea* O. Berg Landrum (Cambuci) as Natural Source of Vitamin C. *Athens J. Sci*. 4(1):37–46. http://dx.doi.org/10.30958/ajs.4-1-3

Lescano, C.H., Lima, F.F. de, Caires, A.R.L., & Oliveira, I.P. de. (2019). Polyphenols Present in *Campomanesia* Genus: Pharmacological and Nutraceutical Approach. 2 ed. Elsevier Inc. Cap 25.

Lescano, C.H., De Lima, F.F., Mendes-Silvério, C.B., Justo, A.F.O., Baldivia, D. da S., Vieira, C.P., Sanjinez-Argandoña, E.J., Cardoso, C.A.L., Mónica, F.Z., & De Oliveira, I.P. (2018). Effect of polyphenols from *Campomanesia adamantium* on platelet aggregation and inhibition of cyclooxygenases: Molecular docking and in vitro analysis. *Front. Pharmacol*. 9(617):1–13. https://doi.org/10.3389/fphar.2018.00617

Lewinsohn, T.M., & Prado, P.I. (2005). How many species are there in Brazil? *Conserv. Biol*. 19(3):619–624. http://dx.doi.org/10.1111/j.1523-1739.2005.00680.x

Lima, N.V. de, Arakaki, D.G., Tschinkel, P.F.S., Silva, A.F., Guimarães, R. de C.A., Iane, P.H., Ferreira Júnior, M.A., & Nascimento, V.A. do (2016). First comprehensive study on total determination of nutritional elements in the fruit of the *Campomanesia adamantium* (Cambess.): Brazilian cerrado plant. *Int. Arch. Med*. 9(350):1–11. https://doi.org/10.3823/2221

Limberger, R.P., Apel, M.A., Sobral, M., Moreno, P.R.H., Henriques, A.T., & Menut, C. (2001). Chemical composition of essential oils from some *Campomanesia* species (Myrtaceae). *J. Essent. Oil Res*. 13(2):113–115. https://doi.org/10.1080/10412905.2001.9699630

Macedo, J.G.F., Rangel, J.M.L., Santos, M. de O., Camilo, C.J., Da Costa, J.G.M., & Souza, M.M.de A. (2021). Therapeutic indications, chemical composition and biological activity of native Brazilian species from *Psidium* genus (Myrtaceae): A review. *J. Ethnopharmacol*. 278:114248. https://doi.org/10.1016/j.jep.2021.114248

Machate, D.J., Candido, C.J., Inada, A.C., Franco, B.C., Carvalho, I.R.A. de, Oliveira, L.C.S. de, Cortes, M.R., Caires, A.R.L., Silva, R.H. da, Hiane, P.A., Bogo, D., Lima, N.V. De, Nascimento, V.A. do, Guimarães, R. de C.A., & Pott, A. (2020). Fatty acid profile and physicochemical, optical and thermal characteristics of *Campomanesia adamantium* (Cambess.) O. Berg seed oil. *Food Sci. Technol*. 40(2):538-544. https://doi.org/10.1590/fst.32719

Marin, R., Apel, M.A., Limberger, R.P., Raseira, M.C.B., Pereira, J.F.M., Zuanazzi, J.Â.S., & Henriques, A.T. (2008). Volatile components and antioxidant activity from some myrtaceous fruits cultivated in Southern Brazil. *Lat. Am. J. Pharm*. 27(2):172–177.

Medino, I., Tonini, I.G.O., Amaral, L.A., Loubet Filho, P.S., Santos, E.F., & Novello, D. (2019). Cookie adicionado de farinha de resíduos de Guavira: Composição físico-química e análise sensorial. *Evidência* 19(1):7–22. https://doi.org/10.18593/eba.v19i1.20287

Mendes, K.D.S., Silveira, R.C.C.P., & Galvão, C.M (2019). Use of the bibliographic reference manager in the selection of primary studies in integrative reviews. *Texto & Contexto-Enfermagem*. 28(e20170204).

Menezes Filho, A.C.P. de, Sousa, W.C. de, & Castro, C.F. de S. (2020). Composição química, físico-química e atividade antifúngica dos óleos essenciais da flor e do fruto de *Myrcia guianensis* (Aubl.) DC. *Rev. Principia - Divulg. Científica e Tecnológica do IFPB* 1(52):92-104.

Menezes, I.A.C., Barreto, C.M.N., Antoniolli, Â.R., Santos, M.R.V. & De Sousa, D.P. (2010). Hypotensive activity of terpenes found in essential oils. *Zeitschrift fur Naturforsch*. C 65(9–10):562–566. https://doi.org/10.1515/znc-2010-9-1005

Mittermeier, R.A., Gil, P.R., & Mittermeier, C.G. (1997). Megadiversity: Earth's biologically wealthiest nations. Cemex, Mexico.

Mourabit, N., Arakrak, A., Bakkali, M., Bakrim, H., Hilal, B. & Laglaoui, A. (2020). Antibacterial activity of the essential oils against multiresistant bacterial strains isolated from hospital. *J. Anal. Sci. Appl. Biotechnol* 2(2):92–98. https://doi.org/10.48402/IMIST.PRSM/jasab-v2i2.23840

Nascimento, K.F. do, Moreira, F.M.F., Alencar Santos, J., Kassuya, C.A.L., Croda, J.H.R., Cardoso, C.A.L., Vieira, M. do C., Góis Ruiz, A.L.T., Ann Foglio, M., Carvalho, J.E. de, & Formagio, A.S.N. (2018). Antioxidant, anti-inflammatory, antiproliferative and antimycobacterial activities of the essential oil of *Psidium guineense* Sw. and spathulenol. *J. Ethnopharmacol*. 210:351–358. http://dx.doi.org/10.1016/j.jep.2017.08.030

Oliveira, J.D., Alves, C.C.F., Miranda, M.L.D., Martins, C.H.G., Silva, T.S., Ambrosio, M.A.L.V., Alves, J.M., & Silva, J.P. (2016). Rendimento, composição química e atividades antimicrobiana e antioxidante do óleo essencial de folhas de *Campomanesia adamantium* submetidas a diferentes métodos de secagem. *Rev. Bras. Plantas Med*. 18(2):502–510. https://doi.org/10.1590/1983-084X/15_206

Oliveira, J.D. de, Alves, D.K.M., Miranda, M.L.D., Alves, J.M., Xavier, M.N., Cazal, C. de M., & Alves, C.C.F. (2017). Chemical composition of essential oil extracted from leaves of *Campomanesia adamantium* subjected to different hydrodistillation times. *Ciência Rural* 47(1):1–7. https://doi.org/10.1590/0103-8478cr20151131

Oliveira, V. S.; Argandoña, E. J. S., & Oshiro, A.M. (2018). *Atomização e liofilização da polpa de Campomanesia adamantium: influência das variáveis de processo na retenção de vitamina C*. Campo Grande: Novas Edições Acadêmicas.

Pacheco, L.A., Ethur, E.M., Sheibel, T., Buhl, B., Weber, A.C., Kauffmann, C., Marchi, M.I., Freitas, E.M., & Hoehne, L. (2021). Chemical characterization and antimicrobial activity of *Campomanesia aurea* against three strains of *Listeria monocytogenes*. *Brazilian J. Biol*. 81(1):69–76. https://doi.org/10.1590/1519-6984.219889.

Pascoal, A.C.R.F., Lourenço, C.C., Sodek, L., Tamashiro, J.Y., Franchi, G.C., Nowill, A.E., Stefanello, M.É.A., & Salvador, M.J. (2011). Essential oil from the leaves of *Campomanesia guaviroba* (DC.) Kiaersk. (Myrtaceae): Chemical composition, antioxidant and cytotoxic activity. *J. Essent. Oil Res*. 23(5):34–37. https://doi.org/10.1080/10412905.2011.9700479

Peres, C.A. (2005). Why We Need Megareserves in Amazonia. *Conserv. Biol*. 19(3):728–733. http://dx.doi.org/10.1111/j.1523-1739.2005.00691.x

Piccinelli, A.C., Santos, J.A., Konkiewitz, E.C., Oesterreich, S.A., Formagio, A.S.N., Croda, J., Ziff, E.B., & Kassuya, C.A.L. (2015). Antihyperalgesic and antidepressive actions of (R)-(+)-limonene, α-phellandrene, and essential oil from *Schinus terebinthifolius* fruits in a neuropathic pain model. *Nutr. Neurosci.* 18(5):217–224. https://doi.org/10.1179/1476830514Y.0000000119

Projeto Mapbiomas. (2021). Coleção 6.0 da Série Anual de Mapas de Uso e Cobertura da Terra do Brasil. https://plataforma.brasil.mapbiomas.org.

Radünz, M., Trindade, M.L.M. da, Camargo, T.M., Radünz, A.L., Borges, C.D., Gandra, E.A., & Helbig, E. (2019). Antimicrobial and antioxidant activity of unencapsulated and encapsulated clove (*Syzygium aromaticum*, L.) essential oil. *Food Chem*. 276:180–186. https://doi.org/10.1016/j.foodchem.2018.09.173

Rao, J., Chen, B., & Mcclements, D.J. (2019). Improving the efficacy of essential oils as antimicrobials in foods: mechanisms of action. *Annu. Rev. Food Sci. Technol*. 10:365–387. https://doi.org/10.1146/annurev-food-032818-121727

Raven, P.H., Evert, R.F., & Eichhorn, S. (2007). *Biologia vegetal*. 7 ed. Guanabara Koogan, Rio de Janeiro.

Reis, A.F., & Schmiele, M. (2019). Características e potencialidades dos frutos do Cerrado na indústria de alimentos. *Brazilian J. Food Technol*. 22: e2017150. https://doi.org/10.1590/1981-6723.15017

Santana, N.A., Silva, R.C.S.da, Fourmentin, S., Anjos, K.F.L. dos, Ootan, M.A., Silva, A.G. da, Pereira Araújo, B.G., Santos Correia, M.T. dos, Silva, M.V. da, & Machado, G. (2020). Synthesis, characterization and cytotoxicity of the *Eugenia brejoensis* essential oil inclusion complex with β-cyclodextrin. *J. Drug Deliv. Sci. Technol*. 60:101876. https://doi.org/10.1016/j.jddst.2020.101876

Schneider, V.S., Bark, J.M., Winnischofer, S.M.B., Santos, E.F. dos, Iacomini, M., & Cordeiro, L.M.C. (2020). Dietary fibres from guavira pomace, a co-product from fruit pulp industry: characterization and cellular antioxidant activity. *Food Res. Int*. 132:109065. https://doi.org/10.1016/j.foodres.2020.109065

Sá, S., Chaul, L.T., Alves, V.F., Fiuza, T.S., Tresvenzol, L.M.F., Vaz, B.G., Ferri, P.H., Borges, L.L., & Paula, J.R. (2018). Phytochemistry and antimicrobial activity of *Campomanesia adamantium*. *Brazilian J. Pharmacogn*. 28(3):303–311. https://doi.org/10.1016/j.bjp.2018.02.008

Santos, A.L. dos, Polidoro, A. Dos S., Cardoso, C.A.L., Batistote, M., Do Carmo Vieira, M., Jacques, R.A., & Caramão, E.B. (2019). GC×GC/qMS analyses of *Campomanesia guazumifolia* (Cambess.) O. Berg essential oils and their antioxidant and antimicrobial activity. *Nat. Prod. Res*. 33(4):593–597. https://doi.org/10.1080/14786419.2017.1399383

Santos-Sánchez, N.F., Salas-Coronado, R., Villanueva-Cañongo, C., & Hernández-Carlos, B. (2019). Antioxidant compounds and their antioxidant mechanism. Antioxidants. IntechOpen, London.

Shishir, M.R.I., Xie, L., Sun, C., Zheng, X., & Chen, W. (2018). Advances in micro and nano-encapsulation of bioactive compounds using biopolymer and lipid-based transporters. *Trends Food Sci. Technol*. 78:34–60. https://doi.org/10.1016/j.tifs.2018.05.018

Siddique, S., Parveen, Z., Firdaus-E-Bareen, & Mazhar, S. (2020). Chemical composition, antibacterial and antioxidant activities of essential oils from leaves of three *Melaleuca* species of Pakistani flora. *Arab. J. Chem*. 13(1):67–74. http://dx.doi.org/10.1016/j.arabjc.2017.01.018

Silva, A.N., Uetanabaro, A.P.T., & Lucchese, A.M. (2013). Chemical composition and antibacterial activity of essential oils from *Myrcia alagoensis* (Myrtaceae). *Nat. Prod. Commun*. 8(2):269–271. https://doi.org/10.1177%2F1934578X1300800235

Silva, C.G.F., Lucas, A.M., Santo, A.T. do E., Almeida, R.N., Cassel, E., & Vargas, R.M.F. (2019a). Sequential processing of *Psidium guajava* L. leaves: steam distillation and supercritical fluid extraction. *Brazilian J. Chem. Eng*. 36(1):487–496. https://doi.org/10.1590/0104-6632.20190361s20170215

Silva, H. D. M., Perfeito, D. G. A., Silva, A. R., & Peixoto, N. (2017). Caracterização e estudo da estabilidade física de suco misto adoçado de mangaba e cagaita. *Revista de Agricultura Neotropical*, 4(2):81-87. http://dx.doi.org/10.32404/rean.v4i2.1542

Silva, J.R.M., Cardoso, C.A.L., & Re-Poppi, N. (2009a). Essential oil composition of the leaves of *Campomanesia pubescens*. *Chem. Nat. Compd*. 45(4):565–567. http://dx.doi.org/10.1007/s10600-009-9368-0

Silva, J.R.M., Ré-Poppi, N., & Cardoso, C.A.L. (2009b). Fruit oil of *Campomanesia pubescens* (Myrtaceae). *J. Essent. Oil Res*. 21(4):315–316. http://dx.doi.org/10.1080/10412905.2009.9700180

Silva, L.E., Amaral, W. Do, Deschamps, C., Biasi, L.A., Bizzo, H.R., & Pinto, M.A.S. (2019b). Essential oil yield and composition of native species of the Myrtaceae family from "Campos Gerais" of the Atlantic Forest in Parana State. *Ciência e Nat*. 41:e45. http://dx.doi.org/10.5902/2179460X40405

Silva, L.E., Gonçalves, M.V.S., Amaral, W.A. do, Quadros, D.A. de, Reis, R.A., Amaral, L.D.P. do, Huergo, L.F., & Garcia, B.(2018). Chemical composition and antibacterial activity of *Cymbopogon citratus* and *Cymbopogon flexuosus* essential oils. *Ciência e Nat*. 40:e2. http://dx.doi.org/10.5902/2179460X27569

Simões, C. M. O., & Spitzer, V. (2000). Óleos voláteis. In: *Farmacognosia*. UFRGS, Porto Alegre/RS.

Souza, J.L. da C., Silva, L.B. E, Reges, N.P.R., Mota, E.E.S., & Leonídio, R.L. (2019). Caracterização física e química de gabiroba e murici. *Rev. Ciências Agrárias* 42(3):221–230. https://doi.org/10.1590/0100-2945-036/14

Stefanello, M.É.A., Cervi, A.C., Wisniewski, A., & Simionatto, E.L. (2008). Essential oil composition of *Campomanesia adamantium* (Camb) O. Berg. *J. Essent. Oil Res*. 20(5):424–425. https://doi.org/10.1590/0103-8478cr20151131

Teixeira, N., Melo, J.C.S., Batista, L.F., Paula-Souza, J., Fronza, P., & Brandão, M.G.L. (2019). Edible fruits from Brazilian biodiversity: A review on their sensorial characteristics versus bioactivity as tool to select research. *Food Res. Int*. 119:325-348. https://doi.org/10.1016/j.foodres.2019.01.058

Vallilo, M.I, Bustillos, O.V., & Aguiar, O.T.de (2006a). Identificação de terpenos no óleo essencial dos frutos de *Campomanesia adamantium* (Cambessédes) O. Berg. - Myrtaceae. *Rev. Inst. Flor*. 18:15-22.

Vallilo, M.I., Lamardo, L.C.A., Gaberlotti, M.L., Oliveira, E., & Moreno de, P.R.H. (2006b). Composição química dos frutos de *Campomanesia adamantium* (Cambessédes) O. Berg. *Cienc. e Tecnol. Aliment*. 26(4):805–810. http://dx.doi.org/10.1590/S0101-20612006000400015

Vasconcelos, L.C., Santos, E. de S., Mendes, L.A., Ferreira, M.F. da S., & Praça-Fontes, M.M. (2021). Chemical composition, phytotoxicity and cytogenotoxicity of essential oil from leaves of *Psidium guajava* L. cultivars. *Res. Soc. Dev*. 10(9):e6110917710. https://doi.org/10.33448/rsd-v10i9.17710

Viscardi, D.Z., Arrigo, J.D.S., Correia, C.A.C. de, Kassuya, C.A.L., Cardoso, C.A.L., Maldonade, I.R., & Argandoña, E.J.S. (2017a). Seed and peel essential oils obtained from *Campomanesia adamantium* fruit inhibit inflammatory and pain parameters in rodents. *PLoS One* 12(2):1–15. https://doi.org/10.1371/journal.pone.0157107

Viscardi, D.Z., Oliveira, V.S. de, Arrigo, J.da S., Piccinelli, A.C., Cardoso, C.A L., Maldonade, I.R., Kassuya, C.A.L., & Sanjinez-Argandoña, E.J. (2017b). Anti-inflammatory, and antinociceptive effects of *Campomanesia adamantium* microencapsulated pulp. *Brazilian J. Pharmacogn* 27:220 – 227. http://dx.doi.org/10.1016/j.bjp.2016.09.007