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Review Article

Biotechnological and socio-environmental potential of *Campomanesia adamantium* (Myrtaceae): an interdisciplinary review

O potencial biotecnológico e sócio-ambiental da *Campomanesia adamantium* (Myrtaceae): uma revisão interdisciplinar

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Abstract

Guavira (*Campomanesia adamantium*, Myrtaceae) is a native fruit from the Brazilian Cerrado savanna and is socio-economically important for the indigenous and traditional people living in the Central-West. This is a bibliographic review of the biological properties of guavira and its derivatives, and, after discussing experimental studies, an interdisciplinary approach is conducted highlighting the im-portance of Agroforestry Systems as an ecological restoration tool to leverage the production chain of guavira while providing ecosystem services. Many research groups studied effects of polyphenols and other bioactive compounds and biological properties of this fruit and other plant parts such as antibiotic, antioxidant, anti-inflammatory, anti-hyperlipidemic, anti-diarrheic and antitumoral activities, cardiovascular and hepatic protection and action against neuropathic pain. Besides, guavira by-products benefit poultry intestinal health, similarly to antibiotics added to their feed. Furthermore, several biotechnological products were found, like pulp flour, seasoning from the peel, sunscreen, and seed oil similar to olive oil with pharmaceutical and industrial potential. We conclude by emphasizing the importance of guavira for restoration and preservation of the threatened Brazilian Cerrado, and for the socio-environmental development of family agriculture. The same approach and study are welcome and necessary in other regions and domains worldwide having their native flora as means for a restorative end.

Keywords: Brazilian Cerrado, guavira, bioactive compounds, ecological restoration, agroforestry systems.

Resumo

Guavira (*Campomanesia adamantium*, Myrtaceae) é um fruto nativo do Cerrado brasileiro e de importância sócio econômica para a população indígena e tradicional do Centro-Oeste. Esta é uma revisão bibliográfica das propriedades da guavira e seus derivados e, após a discussão de estudos experimentais, uma abordagem interdisciplinar é conduzida destacando a importância dos Sistemas Agroflorestais como uma ferramenta de restauração ecológica para alavancar a cadeia produtiva da guavira enquanto fornece serviços ecossistêmicos. Muitos grupos de pesquisa estudaram os efeitos dos polifenóis e outros compostos bioativos e propriedades biológicas desta fruta e de outras partes da planta, como antibióticos, antioxidantes, anti-inflamatórios, anti-hiperlipidêmicos, antidiarreicos e antitumorais, proteção cardiovascular e hepática e ação contra a dor neuropática. Além disso, os subprodutos da guavira beneficiam a saúde intestinal das aves, da mesma forma que os antibióticos adicionados à sua alimentação. Foram, também, encontrados diversos produtos biotecnológicos, como farinha de polpa, tempero da casca, protetor solar e óleo de semente semelhante ao azeite com potencial farmacêutico e industrial. Concluímos enfatizando a importância da guavira para a restauração e preservação do ameaçado Cerrado brasileiro e para o desenvolvimento socioambiental da agricultura familiar. A mesma abordagem e estudo são bem-vindos e necessários em outras regiões e domínios em todo o mundo, tendo sua flora nativa como meio para um fim restaurador.

Palavras-chave: Cerrado, guavira, compostos bioativos, restauração ecológica, sistemas agroflorestais.

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1. Introduction

Guavira (*Campomanesia adamantium* (Cambess.) O. Berg), the symbol-fruit of the state of Mato Grosso do Sul, Brazil, since 2017, merges with the culture and tradition of Central-Western population and with the regional indigenous peoples, being consumed in natura, in several recipes and also being a reason for family reunion and celebration at harvest time in the "guavirais" (natural groupings of the plant mainly in the Cerrado, the Brazilian savanna (Antonio, 2020). Far beyond its historical and cultural importance, its fruit has economic value for local communities that collect and sell it on open-air markets and by the roads, and environmental value, once *C. adamantium* is a typical species of the Brazilian Cerrado.

In the past years, the "guavirais" located in Cerrado and South Pantanal areas in Mato Grosso and Mato Grosso do Sul States have been under threat due to the expansion of agribusiness, mainly beef cattle and large-scale corn and soybean crops (Antonio, 2020), besides sugarcane and eucalyptus (Antonio, 2020). Thus, "guavirais" maintenance is key for those unique biomes (Colli et al., 2020).

According to the International Union of Pure and Applied Chemistry (IUPAC) Goldbook (IUPAC, 2019), biotechnology is an integration of natural and engineering sciences in order to achieve the application of living organisms, parts of them and/or their molecular analogues for products and services development which aims to promote the improvement of life quality for humans and nature. Thus, the biotechnological potential of *C. adamantium* extends through different biotechnological application axes such as health care, *i.e.* pharmaceutical, cosmeceutical and medical purposes, crop production and agriculture, developing more sustainable production models and/or ensuring productivity improvement, non-food (industrial) uses of crops and other products such as vegetable oils and biofuels, nutritional food industry and the one devoted to the problems of environment protection (Kafarski, 2012).

The Organization for Economic Co-operation and Development (OECD) have discussed, since 1982, different issues on biotechnology to promote coordination and cooperation among countries. The last Green Growth Sustainable and Development Forum, held in 2022, addressed on countries and initiatives can balance support for research on new technologies and for the deployment of green technologies already at commercialization stage and how bio-economy sectors could play for a sustainable recovery. For this several recommendations and guidelines were released targeting harmonization of regulatory oversight in biotechnology (OECD, 2022).

Research and identification of bioactive compounds derived from guavira allied with agroforestry models, in addition to the consolidation of its production chain, add to the strategies of this fruit valorization, ecological restoration and environmental preservation, thus following the Union Nations (UN) directives about the Decade on Ecosystem Restoration (2021-2030) where it is utmost being interdisciplinary and inclusive by saving and maintaining native biodiversity and well-functioning ecosystems (Aronson et al., 2020).

This interdisciplinary review on the biotechnological and socio-environmental potential of *C. adamantium* it is first presented the botanical and phenological features of the species followed by a diverse biological activity studied and found in the scientific literature, ranging from antibiotic and anti-inflammatory to antitumoral activities *in vitro* and *in vivo.* Way beyond its biotechnological potential, *C. adamantium* also has features which corroborates with its use on ecological restoration approaches in the Brazilian Cerrado; these features and potentials are also discussed below.

2. Botanical and Phenological Features of *Campomanesia adamantium*

There are about 24 species of *Campomanesia* (Myrtaceae) found in Brazil, from which five species of guavira (*Campomanesia adamantium*, *C. xanthocarpa*, *C. pubescens*, *C. sessiliflora* and *C. eugenioides*) were recorded in Mato Grosso do Sul. Here we focus our literature review on *C. adamantium* characteristics and studies (Landrum, 1986; Bortolotto et al., 2018). Guavira, guabiroba, guabiroba-verde and guabiroba-do-mato are popular synonymous to designate a round yellowish green fruit with a unique citric to sweet flavor which thrives mainly in the Cerrado domain but also extends to borderline countries such as Paraguay and Argentina (Figure 1).

The Cerrado domain, the second largest biome of Brazil and home of important headwaters and unique biodiversity, is characterized by a seasonal climate with two different periods: a wet season between October and March and a dry season between April and September. The average temperature ranges from 22 to 27 °C (Klink and Machado, 2005). The Cerrado physiognomies can be divided first into drylands and wetlands. As part of the drylands, where guavira grows, it is possible to identify grasslands (Campo Limpo), shrubby grasslands (Campo Sujo), woody savannas (Cerrado Sensu Stricto) and seasonal forest (Cerradão); and part of wetlands, wet grasslands (seasonally waterlogged soil by groundwater rise due water table close to the surface), wet shrubby grasslands and regions along river courses in the savanna, such as Veredas, floodplains (Várzeas), Swamps (Brejos), Mauritia groves (Buritizais). Gallery Forests (Matas de galeria), and swamp gallery forests (also Matas de galeria). Veredas are water outcrops on organic soil which originate springs that feed the streams year-round (Durigan et al., 2022).

Guavira is a shrubby deciduous plant. Its flowering season is between August and October, being pollinated mainly by bees, and its fruiting season starts in late October, peaks in November and finishes in January (Vallilo et al., 2006). The morphological features of the plant, leaves, flowers and fruits can be seen in Figure 2.

A 2-year follow-up study in Goiás (also in central-west Brazil) found a moderate to high correlation of sprouting and fruiting with rainfall and air relative humidity and a weak negative correlation with temperature. Those authors point out that high temperatures and low air relative humidity may interfere with pollen tube development after pollination.

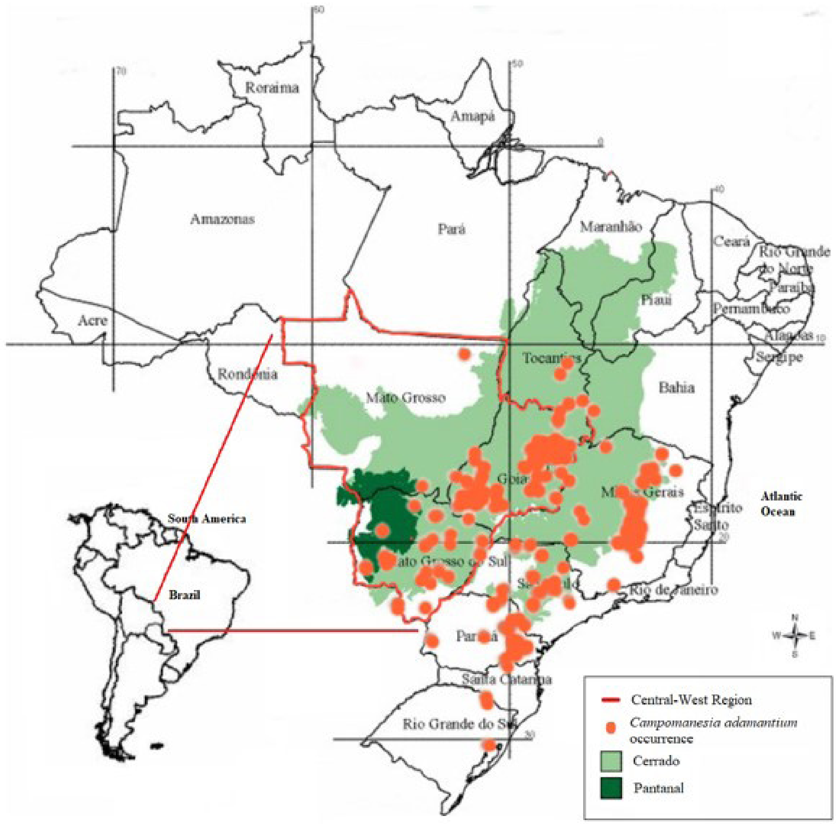

Figure 1. Map of recorded occurrences of *Campomanesia adamantium*, extracted from the Brazilian Biodiversity Information System Database (SIBBr, 2022), overlapping the Brazilian biomes Cerrado and Pantanal. The central-west region of Brazil is highlighted by a red outline and includes the states of Mato Grosso do Sul, Mato Grosso, Goiás e Distrito Federal. Source: Elaborated by the authors.

Figure 2. Morphology characteristics of *Campomanesia adamantium* (Cambess.) O. Berg. Extracted from Durigan et al. (2018).

The mean number of fruits developed per plant was 106 in the first year of study and 60 in the second one; the decreased productivity observed in the second year was explained by an unusually dry November (Leão-Araújo et al., 2019). However, low radiation affects fruit development in this species since, in the same plant, branches that received more sunlight presented more fruits than the shadowed branches (Santos et al., 2020).

Its fruiting coincides with the beginning of the rainy season, which contributes to its natural germination since its seeds are recalcitrant, *i.e.*, they have high water content at maturity but are unable to develop protective mechanisms against dehydration, which restricts their use for sowing soon after fruit extraction (Dresch et al., 2015). Seeds are dispersed mainly by birds and mammals that transport the seeds in their gastrointestinal tract when feeding on the fruit, which contributes to colonization over long distances (Fagundes et al., 2016). Since seeds of *C. adamantium* do not withstand storage due to their desiccation sensitivity, difficulties in maintaining them in seed banks and propagating cultivars are an ecologically and financially valid concern. Researchers have found that submitting *C. adamantium* seeds to a polyethene glycol (PEG) treatment without the increment of abscisic acid (ABA) followed by fast drying (silica gel) up to 15% of water content was able to stimulate protective mechanisms against damage caused by desiccation (Dresch et al., 2017).

Knowledge of phenological features and how to domesticate and manage plant species with ecological, restorative and pharmaceutical importance is fundamental to developing a processing and productive chain properly. In the next section (Section 3), the potential for biotechnological products of guavira is presented, followed by its ecological importance in Cerrado restoration (Section 4).

3. The Potential for Biotechnological Products of *Campomanesia adamantium*: from the Fields to the Lab

Initially, there were extensive areas of native populations called "guavirais" by the original people from Brazil's Central-West region where, during every fruiting season, families and communities gather and celebrate collecting fruits to sell on open-air markets to prepare juices, liquors, ice creams, jellies and jams or to consume them in natura (Vallilo et al., 2006; Antonio, 2020). Traditional people also use the plant for medical purposes such as teas, ointments and sitz baths when not only fruits are required but also leaves, barks and roots. Ethnopharmacological studies have identified several medicinal purposes such as anti-diarrheic, antirheumatic, antimicrobial, anti-inflammatory and against stomachaches (Stefanello et al., 2011).

Several studies have been developed to identify biological properties using different kinds of extracts and isolated compounds from different parts of the plant. These studies and findings are summarized in Table 1 and range from antibiotic, anti-diarrheic and anti-inflammatory to antitumoral, antioxidant and antihyperlipidemic effects among others.

3.1. Antibiotic properties

The antibiotic properties of *C. adamantium* fruit extracts and their fractions were first studied by Pavan et al. (2009) and Cardoso et al. (2010). The first study tested ethyl acetate extracts and their fractions (flavanones and chalcones) on *Mycobacterium tuberculosis* strains and observed a minimal inhibitory concentration (MIC) of 62.5 µg/mL for the ethyl acetate extract. The authors also observed a synergistic inhibitory effect when testing a mixture of two fractions, that contained high level of 5,7-dihydroxy-6,8-di-C-methyl-flavanone and 2',4'-dihydroxy-3',5'-dimethyl-6'-methoxy-chalcone ranging from MICs of 62.5 to 7.8 µg/mL. Meanwhile, Cardoso et al. (2010) focused on the antibiotic activity of fruit hexanic extracts and their fractions against six different microorganisms: *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Salmonella setubal*, *Saccharomyces cerevisiae* and *Candida albicans*. The hexanic extract and its fractions presented MICs ranging from 5 to 20 µg/mL for all microorganisms tested, where *C. albicans* demonstrated to be the most sensitive (MIC = 5 µg/mL) and E. coli, the most resistant (MIC = 20 µg/mL) in the tested panel. When studying the effect of essential oil (EO) from *C. adamantium* leaves, Coutinho et al. (2009) compared antibiotic potential of EOs extract in different phenological stages. The research group found that EOs from the flowering and fruit-bearing stage had a higher antimicrobial activity against *S. aureus*, *P. aeruginosa*, *E. coli* and *C. albicans* when compared with extracts acquired during vegetative stage. This difference may be due to distinct chemical compositions found in EOs acquired during flowering and fruit-bearing stage, which had larger amounts of monoterpenes, with allylic groups and ether, alcohol, aldehydes, ketones, esters and phenols than EOs isolated during vegetative stage. The main constituents of different phenological stages essential oils were classified as monoterpenes and sesquiterpenes changing their percentages according to the phenological stages; during the flowering stage, main constituents were limonene (22.24%), α-pinene (13.23%) and β-pinene (8.99%), while during fruit-bearing stage were bicyclogermacrene (18.95%), germacrene D (11.82%) and β-caryophyllene (8.97%) and, during vegetative stage, the main constituents found were bicyclogermacrene (16.17%), globulol (11.05%) and β-caryophyllene (6.12%). In addition, another study found a moderate inhibition of aerobic strains of *Streptococcus sp.* (MIC ranging from 100 to 400 µg/mL) and of *Bacteroides fragilis*, an anaerobic bacterium (MIC = 400 µg/mL) (Oliveira et al., 2016). According to Oyedemi et al. (2009), essential oils exert antibacterial action by disrupting the outer membrane due lipophilic properties of EO constituents once they observed, when testing γ-terpinene, α -terpinene and eugenol against *Listeria monocytogenes*, *Streptococcus pyogenes*, *Proteus vulgaris* and *E. coli*, lipid and protein leakage, pH changes and ionic disruption of bacteria membrane.

The antidiarrheic property was also verified when the inhibition of heat-stable enterotoxins was promoted by polyphenols derived from the methanolic fruit peel extract.

Table 1. Compiled of studies on *Campomanesia adamantium* biological properties *in vitro* and *in vivo* available at scientific databases.

Biological property	Part of the Plant	Bioactive Compound/Extract	Main Chemical Constituents	Effective Concentration Tested	Results	Reference
Anti-diarrheic	Peel	Methanolic extract	Flavonoids and phenolic compounds	10 mg/mL	Heat-stable enterotoxins inhibition.	Lescano et al. (2016)
Antibiotic	Leaf	Essential oil (EO)	Limonene, α-pinene and β-pinene (flowering stage); bicyclogermacrene, globulol, germacrene D and β-caryophyllene (fruit-bearing and vegetative stages)	MIC ranging from 2 to 26 μg/mL	*Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Candida albicans* growth inhibition.	Coutinho et al. (2009)
	Fruit	Ethyl acetate extracts and their fractions	5,7-dihydroxy-6,8-di-C-methyl-flavanone and 2',4'-dihydroxy-3',5'-dimethyl-6'-methoxy-chalcone	MIC ranging from 62.5 to 7.8 μg/mL	Anti-*Mycobaterium tuberculosis* property.	Pavan et al. (2009)
	Fruit	Hexane extract and its fractions	α-pinene, spathulenol, β-eudesmol, γ-cadinene and γ-muurolene	MIC ranging from 5 to 20 μg/mL	*Staphylococcus aureus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Salmonella setubal*, *Saccharomyces cerevisiae* and *Candida albicans* growth inhibition.	Cardoso et al. (2010)
	Leaf	Essential oil (EO)	Spathulenol (19.27%), germacrene-B (18.27%) and β-caryophyllene oxide (12.37%)	MIC ranging from 100 to 400 μg/mL	Moderate antibacterial inhibition of multiple *Streptococcus* strains (gram-positive) and *Bacteroides fragilis* (gram-negative).	Oliveira et al. (2016)
Anti-inflammatory	Leaf	Ethyl acetate (EA) and aqueous extracts and EA fractions	Myricitrin, myricetin and quercetin from EA extract (flavonoids). Components from aqueous extract were not cited.	*In vivo* experiments: 125 mg/kg (AE) and 250 mg/kg (aqueous extract). Inhibition of NO: 320 μg/mL (AE), 6.25 μM (Myricitrin and Myricetin). Inhibition of TNF-α: 320 μg/mL (AE), 100 μM (Myricitrin) and 25 μM (Myricetin). IL-10 production: 160 μg/mL (AE), 25 μM (Myricitrin) and 50 μM (Myricetin).	Inhibition of carrageenan-induced paw oedema and reduction of time to licking of formalin method and the number of writhes in mice. *In vitro* inhibition of NO and TNF-α production by macrophages and increased production of IL-10 by macrophages.	Ferreira et al. (2013)
	Peel	Methanolic extract	Flavonoids and phenolic compounds	1 mg/mL	*In vitro* COX-1 and COX-2 inhibition.	Lescano et al. (2016)
	Bark	Hydroethanolic extract	Aqueous fraction: myricitrin. Methanolic fraction: quercetin, myricetin, 5,7-dihydroxy-6-methylflavanone, 5,7-dihydroxy-8-mthylflavanone and 2',4'-dihydroxy-6'-methoxychalcone. Ethyl acetate fraction: 7-hydroxy-5-methoxy-6-methylflavanone, 5,7-dihydroxy-6,8-dimthylflavanone and 2',4'-dihydroxy-3',5'-dimethyl-6'-methoxychalcone.	100 mg/kg (inhibition of leukocyte migration) and 300 mg/kg (inhibition of protein leakage).	Inhibition of leukocyte migration and protein leakage.	Souza et al. (2017)
	Seed and Peel	Essential oils (EO)	Seed EO: limonene (20.89%) and β-pinene (11.48%). Peel EO: limonene (13.07%) and thujopsene (6.96%).	100 mg/kg for both EO tested.	Inhibition of leukocyte migration, paw oedema and 1st and 2nd phases of formalin-induced nociception (inflammatory and neurogenic pain).	Zuntini Viscardi et al. (2017)
	Peel	Methanolic extract and isolated flavonoids (quercetin and myricetin)	5,7-dihydroxy-6-methylflavanone, 5,7-dihydroxy-8-methylflavanone, 2′,4′dihydroxy 6′-methoxychalcone, 7-hydroxy-5-methoxy-6-methylflavavone, 5,7-dihydroxy-6,8-dimethylflavanone, quercetin, myricetin and 2′,4′-dihydroxy-3′,5′-dimethyl-6′-methoxychalcone	Peel Extract: from 0.25 to 10 mg/mL. Quercetin and myricetin: 10 μM.	Inhibition of COX-1 and platelet aggregation *in vitro*.	Lescano et al. (2018)
	Peel and Pulp	Dichloromethane extracts and isolated dimethylchalcone (DMC) from pulp extract.	Dichloromethane pulp extract: 7-hydroxy-5-methoxy-6-C-methylflavanone, 5,7-dihydroxy-6,8-C-methylflavanone, 5,7-dihydroxy-6,8-C-methylflavanone, 4',6'-dihydroxy-3',5'-dimethyl-2'-methoxychalcone, 4',6'-dihydroxy-3'-methyl-2'-methoxychalcone, champanone C and champanone D.	GI_{50} of pulp extract: 16.17 μg/mL. 50% inhibition of NO release: 25 μg/mL.	Inhibition of NO release of murine intraperitoneal macrophages co-cultured with melanoma murine cells (B16F10).	Silva et al. (2018)

Abbreviation: MIC = minimal inhibitory concentration; NS = not specified; NO = nitric oxide; TNF = tumor necrosis factor; IL = interleukin; COX = cyclooxygenase; NF-Kβ = nuclear factor kappa beta; SNI = spared nerve injury; MDA = malondialdehyde; SSPF = semisolid pharmaceutical formulation; SPF = sun protection factor; AST = aspartate aminotransferase; ALT = alanine aminotransferase; GF = guavira flour; ORAC = oxygen radical absorbance capacity.

Table 1. Continued...

Biological property	Part of the Plant	Bioactive Compound/Extract	Main Chemical Constituents	Effective Concentration Tested	Results	Reference
Anti-oxidant	Leaf	Methanolic extract	7-hydroxy-5-methoxy-flavanone, 7-hydroxy-5-methoxy-6-methylflavanone, 5,7-dihydroxy-6-methylflavanone, 5,7-dihydroxy-8-methylflavanone, 2',4'-dihydroxy-6'-methoxychalcone, 5,7-dihydroxy-6,8-dimethylflavanone, 2',4'-dihydroxy-6'-methoxy-5'-methylchalcone, 2',4'-dihydroxy-6'-methoxy-3'-methylchalcone and 2',4'-dihydroxy-6'-methoxy-3',5'- dimethylchalcone.	Ranging from 80 to 480 µg/mL depending on the region of leaves collection (antioxidant activity). Ranging from 144-160 µg/mL depending on the region of leaves collection (lipid peroxidation inhibition).	High antioxidant activity (DPPH) and lipid peroxidation inhibition.	Coutinho et al. (2008)
	Root	Aqueous extract	Identification of gallic acid and ellagic acid.	Antioxidant capacity (DPPH): starting with 37.3 µg/mL and reaching the maximum activity with 250 µg/mL. Protection against induced hemolysis: from 75 to 125 µg/mL.	High antioxidant activity (DPPH) and lipid peroxidation inhibition.	Espindola et al. (2016)
	Leaf	Ethanolic extract and fractions	Isoquercitrin, quercitrin, myricetin, quercetin, 2',4'-dihydroxy-6'-methoxychalcone, 2',4'-dihydroxy-5'-methyl-6'-methoxychalcone and 2',4'-dihydroxy-3',5'-dimethyl-6'-methoxychalcone.	DPPH: from 7.77 to 13.35 µg/mL. ORAC: from 2648 to 3502 µM of TE/g of extract.	High antioxidant activity (DPPH and ORAC)	Pascoal et al. (2011)
Antitumoral	Leaf and Fruits	Ethanolic extract and isolated chalcone (cardamonin)	Quantification of cardamonin in leaves extract (87.74 µg/mg) and fruits extract (5.4 µg/mg) through UPLC-MS methodology. Isolated chalcone: 2*E*-1-2,4-dihydroxy-6-methoxyphenyl-3-penylprop-2-en-1-one (cardamonin).	GI_{50}: 3.20 µg/Ml (leaf extract), 14.25 µg/mL (fruits extract) and 11.35 µg/mL (isolated cardamonin). Downregulation of NF-Kβ and apoptosis induction: 20 µg/mL.	Antiproliferative activity on prostate cancer cells by downregulating NF-Kβ and apoptosis induction	Pascoal et al. (2014)
	Root and Leaf	Aqueous extract	Root extract: di-hexoside/quinic acid, ellagic acid *O*-pentoside, ellagic acid, *O*-methyl ellagic acid *O*-hexoside, ellagic acid *O*-deoxyhexoside and *O*-methyl ellagic acid sulfate. Leaves extract: di-hexoside/quinic acid, myricetin *O*-pentoside, myricetin *O*-deoxyhexoside, quercetin *O*-pentoside and myricetin *O*-(*O*-galloyl)-pentoside.	IC_{50}: 80 µg/mL (roots extract) and 40 µg/mL (leaves extract).	Apoptotic death of leukemic cells by decreasing the mitochondrial membrane potential, increasing the activation of caspase 9 and 3, and intracellular Ca^{2+} levels.	Campos et al. (2017)
	Peel and Pulp	Dichloromethane extracts and isolated dimethylchalcone (DMC) from pulp extract.	Dichloromethane pulp extract: 7-hydroxy-5-methoxy-6-C-methylflavanone, 5,7-dihydroxy-6,8-C-methylflavanone, 5,7-dihydroxy-6,8-C-methylflavanone, 4',6'-dihydroxy-3',5'-dimethyl-2'-methoxychalcone, 4',6'-dihydroxy-3'-methyl-2'-methoxychalcone, champanone C and champanone D.	GI_{50} of pulp extract: 16.17 µg/mL. Caspase-3 activation: 25 µg/mL.	DMC (isolated from pulp extract) had antiproliferative activity on murine melanoma cells by inducing apoptosis (caspase-3 activation).	Silva et al. (2018)
	Peel	Hydroethanolic extract	*NS*	5 mg/animal	Absence of acute toxicity at 2000 mg/kg *in vivo* and inhibition of murine melanoma cells *in vivo*.	Luiz et al. (2019)
	Leaf	Essential oils (EO)	Spathulenol (19.27%), germacrene-B (18.27%) and β-caryophyllene oxide (12.37%)	IC_{50} ranging from 77.2 to 80.5 µg/mL	Antiproliferative activity against breast, cervical and glioblastoma cell lines and satisfactory selectivity index when compared with lung fibroblast cell line.	Alves et al. (2020)

Abbreviation: MIC = minimal inhibitory concentration; NS = not specified; NO = nitric oxide; TNF = tumor necrosis factor; IL = interleukin; COX = cyclooxygenase; NF-Kβ = nuclear factor kappa beta; SNI = spared nerve injury; MDA = malondialdehyde; SSPF = semisolid pharmaceutical formulation; SPF = sun protection factor; AST = aspartate aminotransferase; ALT = alanine aminotransferase; GF = guavira flour; ORAC = oxygen radical absorbance capacity.

Table 1. Continued...

Biological property	Part of the Plant	Bioactive Compound/Extract	Main Chemical Constituents	Effective Concentration Tested	Results	Reference
Anti-hyperalgesic	Bark	Hydroethanolic extract and its fractions	Aqueous fraction: myricitrin. Methanolic fraction: quercetin, myricetin, 5,7-dihydroxy-6-methylflavanone, 5,7-dihydroxy-8-methylflavanone and 2',4'-dihydroxy-6'-methoxychlacone. Ethyl acetate fraction: 7-hydroxy-5-methoxy-6-methylflavanone, 5,7-dihydroxy-6,8-dimethylflavanone and 2',4'-dihydroxy-3',5'-dinethyl-6'-methoxychalcone.	100 mg/kg	Inhibition of SNI-induced mechanical hyperalgesia.	Souza et al. (2017)
Antidepressant	Bark	Hydroethanolic extract and its fractions	Aqueous fraction: myricitrin. Methanolic fraction: quercetin, myricetin, 5,7-dihydroxy-6-methylflavanone, 5,7-dihydroxy-8-methylflavanone and 2',4'-dihydroxy-6'-methoxychlacone. Ethyl acetate fraction: 7-hydroxy-5-methoxy-6-methylflavanone, 5,7-dihydroxy-6,8-dimethylflavanone and 2',4'-dihydroxy-3',5'-dinethyl-6'-methoxychalcone.	100 mg/kg	Decreased immobility behavior time in the forced swim test.	Souza et al. (2017)
Antihyperlipidemic	Root	Aqueous extract	Identification of gallic acid and ellagic acid.	Protection against lipid peroxidation (MDA dosage): starting with 50 µg/mL with a maximum effect with 500 µg/mL. *In vivo* serum MDA dosage: 200 mg/kg.	Decreased production of MDA in human erythrocytes *in vitro* and serum MDA *in vivo*.	Espindola et al. (2016)
Hepatoprotection	Pulp and Peel/Seed	Hydroethanolic extract	Presence of flavonoids in both extracts.	Hepatoprotection *in vitro* (CCl_4-induced): 800 µg/mL. Hepatoprotection *in vivo*: 1000 µg/mL.	Hepatoprotection *in vitro* (HepG2 cells) against CCl_4-induced toxicity preventing apoptosis and maintenance of AST and ALT levels similar to control group *in vivo*.	Oliveira Fernandes et al. (2015)
	Peel and Seed (industrial residue)	Industrial residue flour as supplementation to hypercaloric diet in vivo.	Fibers and phenolic compounds.	Fiber content: 57.1 ± 1.64 g/100 g GF Total phenolic content: 7,391.09 mg AGE/100 g GF Antioxidant capacity: 2.22 (IC_{50}) and 155.68 µmol/TE.g^{-1} (ORAC). Steatosis attenuation: 2% GF supplementation (20 g/kg).	High total fiber content, phenolic compounds and antioxidant capacity. Steatosis attenuation compared to control group *in vivo*.	Loubet Filho et al. (2020)
Photoprotection	Leaf	Dry ethanolic crude extract	Myricitrin, myricetin, cardamonin, gallic acid and strictane-3,22-diol valonic acid.	Formula containing 4% of *C. adamantium* extract with 4% *C. xanthocarpa* extract.	Extracts presented absorption at UVA and UVB regions and the best formulation was *C. adamantium* in association with SSPF and *C. xanthocarpa* extract with a SPF > 6.	Catelan et al. (2019)

Abbreviation: MIC = minimal inhibitory concentration; NS = not specified; NO = nitric oxide; TNF = tumor necrosis factor; IL = interleukin; COX = cyclooxygenase; NF-Kβ = nuclear factor kappa beta; SNI = spared nerve injury; MDA = malondialdehyde; SSPF = semisolid pharmaceutical formulation; SPF = sun protection factor; AST = aspartate aminotransferase; ALT = alanine aminotransferase; GF = guavira flour; ORAC = oxygen radical absorbance capacity.

The proposed mechanism of action relies on the interaction between phenolic compounds and heat-stable enterotoxins which may prevent the interaction of these with guanylate cyclase extracellular domain. In the absence of this extracellular signal, cGMP will not be accumulated inside the cells and the effect of enterotoxins would be attenuated. Meanwhile, the inhibition of *E coli*, *Salmonella typhimurium* and *Staphylococcus aureus* strains was not observed (Lescano et al., 2016).

3.2. Antitumoral properties

The antitumoral properties of *C. adamantium* have been studied on prostate adenocarcinoma cells (PC-3) by Pascoal et al. (2014), where chalcones isolated from *C. adamantium* leaf ethanolic extract induced apoptosis; in leukemic cells (Jurkat) by Campos et al. (2017), where they observed the induction to apoptosis via caspase-3 and activation of intracellular Ca^{2+} with the application of aqueous extract of leaves and roots of *C. adamantium*; and by Silva et al. (2018) in murine melanoma cells (B16F10) with the use of dichloromethane extract and an isolated compound, dimethyl chalcone, from the pulp of *C. adamantium*, where the growth inhibition and apoptosis induction by caspase-3 activation was observed. The main constituents of dichloromethane pulp extracts identified were 7-hydroxy-5-methoxy-6-C-methylflavanone, 5,7-dihydroxy-6,8-C-methylflavanone, 5,7-dihydroxy-6,8-C-methylflavanone, 4',6'-dihydroxy-3',5'-dimethyl-2'-methoxychalcone, 4',6'-dihydroxy-3'-methyl-2'-methoxychalcone, champanone C and champanone D. The concentration which was capable to inhibit 50% of murine melanoma cells growth *in vitro* (GI_{50}) was 16.17 µg/mL for pulp extract and 7.11 µg/mL for isolated dimethyl chalcone isolated from the previous extract. The pulp extract also inhibited 50% of NO release and caspase-3 activation from macrophages with a concentration of 25 µg/mL. The authors proposed, by comparison with previous studies which also used *C. adamantium* extracts or its isolated compounds, that once peel extract was capable to inhibit cGMP, COX-1 and COX-2, thus exerting an anti-inflammatory effect, it could also inhibit the NO production because cGMP is known to be involved in its production and signaling pathway in the tumor microenvironment, being also directly associated with melanoma growth. Another feature is that COX-2 is known to be an effective biomarker for melanoma progression. These finds corroborate with the antitumoral activity of *C. adamantium* extracts over melanoma cells (Bianchini et al., 2007; Dal Monte et al., 2014; Lescano et al., 2016; Silva et al., 2018).

Conversely, Martello et al. (2016), by studying the potential genotoxic effects of the use of hydroethanolic extract from *C. adamantium* leaves alone and in conjunction with cyclophosphamide, a commercial chemotherapic, observed the increase in splenic phagocytosis and splenic, hepatic and renal apoptosis, in addition to inducing DNA damage and inhibiting the action of cyclophosphamide, evidencing a potential genotoxic effect in the use of the tested extract and interference in chemotherapy in mice, which may require caution in its use and more studies on safety. More recently, Luiz et al. (2019) tested the hydroethanolic extract from *C. adamantium* bark on murine melanoma cells (B16F10) and its safety. They observed the inhibition of melanoma cell proliferation *in vitro* and *in vivo* and the absence of acute toxicity (2000 mg/kg) *in vivo*.

Finally, Alves et al. (2020) have found growth inhibitory properties in vitro with essential oils from *C. adamantium* leaves. The essential oils were able to inhibit breast, colon and glioblastoma tumor cells (MCF-7, HeLa and M059J respectively) growth, presenting a mean IC50 of 80 µg/mL and a selectivity index of 4.8, that represents that the tested compound is about 4.8 times more active promoting cell growth inhibition in the tumor cells than in normal cells (pulmonary fibroblasts, GM07492A). These data suggest that the essential oil of guavira leaves is promising for the continuity of studies to assure efficacy and safety using *in vivo* models.

3.3. Antioxidant, anti-inflammatory and metabolic modulation properties

The antioxidant property of guavira extracts was also evaluated by different research groups. Coutinho et al. (2008) found that isolated flavones and chalcones from methanolic extract of guavira leaves presented antioxidant capacity and inhibition of lipid peroxidation. For this, leaves were harvested during the flowering stage of the plant from different regions of Mato Grosso do Sul state. Interestingly, the chemical profile of the distinct regions was qualitatively similar, but quantitatively different what may have affected the effective concentration of the extracts tested. The antioxidant capacity measured by DPPH technique was observed with the use of 80 to 480 µg/mL of methanolic extract depending on the region of leaves collection while the inhibition of lipid peroxidation could be identified using a concentration of 144 or 160 µg/mL, also depending on the region of collection. This variation may be due distinct soil and weather conditions and/or presence of insects and hazards which triggers different physiological responses in the plant contributing with distinct flavonoids concentration in the leaves. The main constituents of leaves' methanolic extracts can be seen in the Table 1. Similar results were found by Pascoal et al. (2011), using leaf ethanolic extract and its ethyl acetic and butanoic fractions, and by Espindola et al. (2016), making use of guavira root aqueous extract. Besides *in vitro* antioxidant capacity measure, Espindola et al. (2016) also verified that the treatment with guavira root aqueous extract and pulp methanolic extract, respectively, contributed to lowering serum lipid peroxidation levels *in vivo* with an effective concentration of 200 mg/kg. Conversely, no antioxidant activity was found in EO from *C. adamantium* leaves *in vitro* (DPPH). The results from Oliveira et al. (2016) corroborate those found by Coutinho et al. (2008), who also attribute the lack of activity to low concentration or absence of secondary metabolites capable of oxygen scavenging. The antioxidant property of a molecule, compound or by-product can be related to chronic inflammatory diseases and cancer development protection once natural molecules such as phenolic compounds may exert protection against oxidative stress and, consequently, protect cells from its consequences: lipid peroxidation, glycation, genotoxicity and malignant transformation (Mendonça et al., 2022).

Regarding the anti-inflammatory action of *C. adamantium* extracts, Ferreira et al. (2013) observed inhibition of carrageenan-induced paw edema and the reduction of time to licking of formalin method and the number of writhes in mice. The affective concentration used during *in vivo* experiments was 125 mg/kg for the ethyl acetic extract of *C. adamantium* leaves and 250 mg/kg for the aqueous extract. It was also observed a decreased production of pro-inflammatory cytokines nitric oxide (NO) and TNF-α and increased production of IL-10 in macrophage sensitized by LPS and IFN-γ when treated with ethyl acetic extract and its fractions identified as myricitrin and myricetin, both flavonoids. The ethyl acetic extract exerted anti-inflammatory action at a concentration of 320 µg/mL, while its fractions presented anti-inflammatory activity at a concentration of 6.25 µM for both flavonoids in NO macrophage reduction and 100 µM (myricitrin) and 25 µM (myricetin) for TNF-α macrophage reduction, while the effective concentration for IL-10 macrophage enhancement was 160 µg/mL for the ethyl acetic extract, 25 µM for myricitrin and 50 µM for myricetin. All results were similar to those observed with the use of dexamethasone, a potent anti-inflammatory widely used. Meanwhile, Souza et al. (2017) used the hydroethanolic extract of *C. adamantium* fruit peel to inhibit leukocyte migration to the mice pleura successfully. They observed the inhibition of leukocyte migration with a dose of 100 mg/kg and the inhibition of protein leakage with a dose of 300 mg/kg. None of these concentrations presented toxicity *in vivo*. The hydroethanolic extract constituents detected by HPLC-DAD analysis were myricitrin in the aqueous fraction, quercetin, myricetin, 5,7-dihydroxy-6-methylflavanone, 5,7-dihydroxy-8-mthylflavanone and 2',4'-dihydroxy-6'-methoxychalcone in the methanolic fraction and 7-hydroxy-5-methoxy-6-methylflavanone, 5,7-dihydroxy-6,8-dimthylflavanone and 2',4'-dihydroxy-3',5'-dimethyl-6'-methoxychalcone in the ethyl acetate fraction. Silva et al. (2018) also observed decreased NO production by macrophages *in vitro* when treated with dichloromethane extract of *C. adamantium* pulp in a dose-dependent way, ranging from 0.25 to 250 µg/mL, without affecting macrophage viability. Zuntini Viscardi et al. (2017) observed the reduction of paw edema, leukocyte migration and neurogenic pain in murine models of inflammation and pain when administered essential oils from *C. adamantium* peel and seed with an effective dose of 100 mg/kg, and, more recently, Lescano et al. (2018) observed the effect of polyphenols, especially quercetin, on the inhibition of platelet aggregation by inhibiting cyclooxygenases-1 and -2, also involved in the main pathway of inflammation, increase in cAMP and cGMP levels, also involved in secondary pathways of inflammation, and decreased mobilization of intracellular Ca^{2+} and thromboxane formation in platelets, postulating the mechanism of anti-inflammatory action and evidencing its protective action against cardiovascular diseases involving the mechanism of platelet aggregation such as thrombosis and atherosclerosis. In this study the effective concentration of quercetin used was 10 µM but the *C. adamantium* peel extract also had effect with concentrations ranging from 0.25 to 10 mg/ml.

Finally, guavira also has shown metabolic effects *in vitro* and *in vivo*, probably due to activation of intracellular anti-inflammatory pathways and antioxidant properties. Beyond the prevention of lipid peroxidation, Espindola et al. (2016) also observed a decreased production of malondialdehyde (MDA) levels in human erythrocytes *in vitro*. The MDA production is linked to lipid peroxidation of cell membrane phospholipids which drives cellular and genetic damage and, in the long-term, organ malfunction and metabolic disbalance. In the same field of investigation, Oliveira Fernandes et al. (2015) had already released their findings on the hepatoprotection properties of the hydroethanolic extract from the pulp, peel and seeds of guavira. They found that human liver cells (HepG2) treated with the extracts were protected against CCl_4-induced toxicity, preventing apoptosis and maintaining AST (aspartate transaminase) and ALT (alanine transaminase) levels, essential enzymes that represent liver function, similar to that of the control group.

More recently, Loubet Filho et al. (2020) performed a diet supplementation with guavira industrial residue (peel and seeds) flour in animals fed with a hypercaloric diet. First, the authors performed the centesimal analysis of the flour and noticed a high fiber (57.1 ± 1.64 g/100 g) and total phenolic compounds (7,391.09 ± 13.72 mg AGE/100 g) content in addition to the assessment of the antioxidant capacity (IC50 = 2.22 ± 0.07; ORAC = 155.68 ± 13.45 µmol/TE g^{-1}). The supplementation has driven non-alcoholic fatty liver disease (steatosis) attenuation compared with the control group ($p < 0.001$) with a 2% guavira residue flour supplementation (20g/kg). These anti-hyperlipidemic effects may be due to the antioxidant capacity of bioactive compounds present in the guavira flour in addition to enhanced fiber, which is also related to microbiota balance and intestinal health by acting as prebiotics, promoting short-chain fatty acids production by bacteria, and improving intestinal peristalsis (Sivaprakasam et al., 2016; Holscher, 2017; Korcz et al., 2018; Loubet-Filho et al., 2020; Zorgetto-Pinheiro et al., 2022).

Enlightened by the findings mentioned above, the use of extracts, isolated compounds and by-products from *C. adamantium* may be promising once several studies point to antioxidant and anti-inflammatory properties, which are known to contribute to the reduction of chronic diseases and their consequences. A schematic chart on how these processes are interconnected and how *C. adamantium* extracts and its by-products might modulate them is proposed in Figure 3.

3.4. Other biological properties

In addition to the anti-inflammatory properties studied by Souza et al. (2017), the researchers also investigated the effects of *C. adamantium* bark extract on the central nervous system and sensibility to pain. The *C. adamantium* bark hydroethanolic extract and its fractions inhibited neuropathic pain caused by mechanically induced spared nerve injury and improved the immobility behavior during a forced swim test *in vivo*, which is associated with an antidepressant activity of the tested compound.

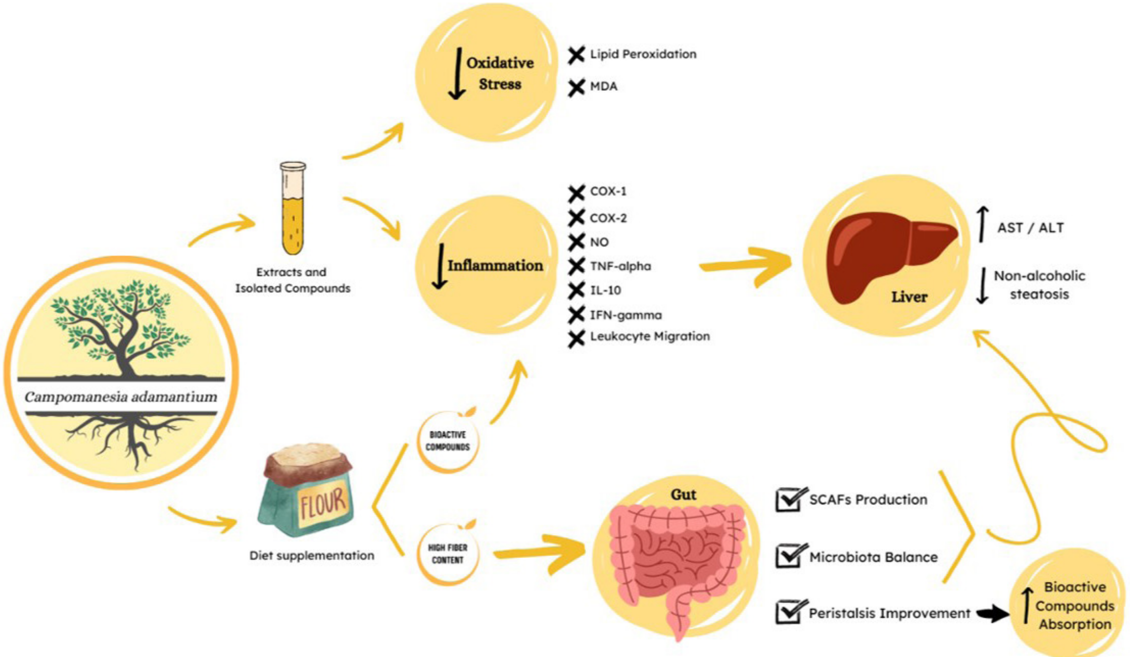

Figure 3. Proposed schematic chart on how biological properties of extracts, isolated compounds and by-products from *Campomanesia adamantium* are interconnected. Source: Based on the reviewed literature and elaborated by the author.

Catelan et al. (2019) investigated the photoprotection capacity of four species of *Campomanesia* associated with a semisolid pharmaceutical formulation (SSPF). The main constituents of the extract were myricitrin, myricetin, cardamonin (2',4'-dihydroxy-6'-methoxy-chalcone), gallic acid and strictane-3,22-diol valonic acid. They noticed that all ethanolic extracts of guavira leaves tested could absorb in the UVA and UVB regions, and the best performance was a mixture of *C. adamantium* 4% with *C. xanthocarpa* 4%, with SSPF presenting a solar protection factor above 6.

Once traditionally guavira has been used in preparations and recipes, the applications of *C. adamantium* by-products or under some processing methodologies have also been studied. The first study aimed to identify the shelf life of powdered *C. adamantium* pulp under controlled environments. This flour stability is of great interest because guavira is a seasonal fruit, and conserving the dehydrated pulp could be an alternative to ensure a natural product available during the whole year. The pulp was dehydrated through the foam mat drying process, packed into low-density polyethene (LDPE) bags and stored under environmental (25 °C, RH 75%) and accelerated (35 °C, RH 90%) conditions for 90 days. Every 10 days, a sample was collected to have some parameters linked to shelf life analyzed (moisture, water activity, vitamin C, pH and titratable acidity). The shelf life of the powdered guavira pulp under environmental conditions was approximately 49 days, and under accelerated conditions, 45 days. The moisture content for these conditions was 10% and 5.4% for 35 °C and 25 °C, respectively (Breda et al., 2012).

In 2019, a patent (BR 102017013777-5 A2) was granted for developing a natural seasoning derived from *C. adamantium* peel after being sanitized, dried and mashed. The patent owner calls attention to its protein content beyond total fiber; both could pro-mote nutraceutical benefits and incorporate several recipes instead of artificial seasonings (Kelm, 2019).

Table 2. Composition of guavira flour (GF) obtained from dried and mashed industrial residue (peel and seeds).

Composition (g / 100 g)	Mean ± *SD*
Moisture	7.19 ± 0.11
Ashes	2.00 ± 0.01
Lipids	2.07 ± 0.07
Protein	1.43 ± 0.14
Dietary fiber	57.10 ± 1.64
Soluble fiber	4.77 ± 2.71
Insoluble fiber	52.33 ± 1.77
Carbohydrates	30.21 ± 0.11
Antioxidant capacity (IC50)	2.22 ± 0.07
Total phenolic content (mg GAE/100 g GF)	7,391.09 ± 13.72
ORAC (µmol/TE g^{-1})	155.68 ± 13.45

Abbreviation: *SD* = standard deviation; GAE = gallic acid equivalent; ORAC = oxygen radical absorbance capacity; TE = Trolox equivalent. **Source:** Loubet Filho et al. (2020).

When studying the effects of diet supplementation with industrial residues of guavira (seeds and peel) processed as flour on metabolic parameters *in vivo*, Loubet Filho et al. (2020) also performed a centesimal analysis of the acquired flour. (Table 2) and called attention to its high fiber and total phenolic compounds content, which is known to promote human health as previously described.

Not only human health has been sought, but also alternatives for better and healthier animal feed which could avoid the use of synthetic adjuvants for growth, performance and meat quality. One of these practices is the routine poultry use of low-dose antibiotics to manipulate the intestinal health of broiler chickens, enhancing nutrient absorption and assimilation, thus reducing feed costs, but which is also correlated with the development of bacterial resistance in humans. Thus, Lohmann et al. (2021) aimed to assess the effects of guavira peel hydroethanolic extract (GPHE) on the performance and meat quality of broilers. Crescent concentrations of *C. adamantium* peel extract (0 to 500 mg/kg) were given to broilers in the finishing phase (from 21 to 42 days), and several parameters were assessed. Those authors found an improvement in weight gain (WG) and fed conversion ratio (FCR), with the greatest WG and FCR being calculated at 314 and 219 mg/kg, respectively. There was also an improvement in water-holding capacity and in MDA content at 30-day storage. Even without improvement in meat quality, broilers fed with diets containing GPHE performed better than the control. Polyphenols and flavonoids, bioactive compounds found in the extract, are able to improve intestinal health, influence digestive processes and modulate the animal immune system and, consequently, may improve meat quality and poultry performance through reducing the lipid oxidation process by neutralizing oxidative stress. Diet supplementation with those bioactive compounds could drive similar or approximate results found when using performance-enhancing antibiotics (Lohmann et al., 2021).

Another feasible guavira by-product is its seed oil which was analyzed by Machate et al. (2020). The results point out that guavira seed oil has similar characteristics to edible vegetable oils such as olive oil, palm oil, and coconut oil, in addition to the presence of bioactive compounds mentioned later in previous studies, making it a great candidate in human utilization for cooking purpose, as well as for soap, lotions and biofuel production.

However, the biotechnological development of a bioproduct, be it for pharmaceutical or food industry purposes or even biofuels, is of no use if its extraction is not done in a sustainable way. Understanding and respecting the guavira phenological cycles and the traditional knowledge of indigenous and traditional peoples is key to the sustainable development of the Central-West region of Brazil and, concurrently, maintaining and replenishing natural capital (Aronson et al., 2020).

4. The Agroforestry Model Enabling the Ecosystem Restoration

The United Nations (UN) General Assembly has declared 2021-2030 as the “Decade on Ecosystem Restoration” and calls for not only for environmental protection increase but also nature restoration by reversing degradation with the aid of diverse management strategies (Aronson et al., 2020; UN, 2021).

According to the UN Environment Programee, 26-40% of the Earth is related to Savannas and Grasslands biomes, which includes the Brazilian Cerrado and Pantanal. Together, those biomes can stock organic carbon in the soil, regulate water resources, feed livestock and host fauna and flora biodiversity hotspots. Conversely, intense agriculture and animal farming have transformed about 70% of savannas worldwide, putting at risk biodiversity still in discovery, indigenous culture and ethnic minorities, who depend on family farming for survival, and contributing to the acceleration of climate change (Foley et al., 2011; Gann et al., 2019; Aronson et al., 2020; Dudley et al., 2020; Mbaabu et al., 2020; UN, 2021). Recently, a study conducted in the Amazon region demonstrated that the presence of organizations of social and solidarity economy, in the form of family farming, are essential to achieve a sustainable development, that is providing economic development and food security for the local population, and agrobiodiversity protection for the region (Mariosa et al., 2022).

Ecological restoration, being part of a restorative continuum, can be assessed by reaching six key ecosystem attributes: absence of threats, physical conditions of the field, species composition, structural diversity, ecosystem function and external changes; the intended endpoint is to make the transition from a degraded ecosystem to a reference one which may gather nature, culture and sustainability. Therefore, stake-holders and government policies may chart partnerships with farmers and the local population living and depending on family agriculture in the surrounding areas (Gann et al., 2019). One example of government investment is tax incentives to landowners who plant native species instead of exotic ones. Using native species also promotes increased plantation productivity with the restorative capacity bonus (Mansourian et al., 2019; N’Woueni and Gaoue, 2022).

It has already been verified that the use of exotic species to provide afforestation and ecological services, such as *Pinus* and *Eucalyptus* species, may seem like an eco-logically correct and financially pleasing solution in the short-term since they present rapid growth (increasing carbon retention and avoiding soil erosion) and the correct destination for the cellulose industry for example. On the other hand, those planted forests are related to a decreased biodiversity, issues with pollinators and pollination of native flora, soil and groundwater depletion due to decreased percolation and increased evapotranspiration rates, and microclimatic alterations (Majer and Recher, 1999; Benayas and Bullock, 2012; Feng et al., 2012; Lü et al., 2012; Guerino et al., 2022; Silva et al., 2022).

Moreover, AFS promote, once is part of the agroecology and adaptive management strategies, crop diversification, enhancing the local biodiversity, reintroduction of native species and environmental recovery, improving soil fertility, and pest and disease regulation making agricultural properties more resilient and resistant to climate changes and contributing to the sustainable development goals (Benayas and Bullock, 2012; Bybee-Finley and Ryan, 2018; Huang et al., 2022; Huss et al., 2022). An ethnobotanical study conducted in Madagascar more than 20 years ago aimed to identify species with potential for use in AFS, improve locals’ nutrition and restore biological diversity. A list of 26 priority species was elaborated and, among them, individuals of *Myrtaceae* family were identified: *Eugenia sp*. and *Syzygium sp*., classified as indigenous species, and *Psidium guajava*, *Psidium cattleianum*, *Eugenia jambolana* and *Eugenia jambos*, classified as exotic and naturalized species.

The authors drew attention to the presence of the traditional knowledge in the rural population who lives in close relationship with the forest and that while the devastation of native vegetation expands, the traditional knowledge and management skills of natural resources are being progressively lost and ties their recommendations with the importance of indigenous fruits to provide income for small farmers, contribute to food security and provide ecological restoration (Styger et al., 1999). Important actors in the concept of ecological and environmental services are the production of biomass and the carbon sequestration potential. AFS, especially those that integrate fruit trees, have a higher capacity of carbon storage aboveground (plants) and below-ground (roots/soil microorganisms) than pastures or field crops, thus being a good source of earning significant carbon credit to the farmers while providing employment generation, additional income to small producers, substantial livelihood support and also aid in on-farm conservation of germplasms and traditional culture (Panwar et al., 2022).

Cerrado is a vital water resource once it bears headwaters and the most extensive portion of South American watersheds. Pesticides and fertilizers have been used in Cerrado soil for agriculture to be possible once the soil is naturally poor, acidic and with a high aluminum content. Consequently, watersheds receive high contents of toxic substances and are subject to eutrophication. Moreover, the wetlands of Cerrado can be considered "kidneys" of the environment because, when rainwater percolates slowly into the deep soil, it is filtered and reaches the groundwaters and, in the so-called replenishment zones, the aquifer. Groundwater has primary relevance on wetland pulses, which is indispensable to biodiversity maintenance. Thus, the Cerrado underground can be considered a large water reservoir, the Guarani Aquifer System (Klink and Machado, 2005; Vallilo et al., 2006; Sindico et al., 2018; Latrubesse et al., 2019).

Using native/indigenous fruits can be an option to improve people's health and value the natural resources available in the Cerrado, increasing the income of small rural communities and contributing to the conservation of native species. The supply of guavira can no longer depend on extractivist harvesting; it has to be cultivated, and it fits into small farming and AFS. The productivity and phenological characteristics of *C. adamantium* intercropped with three different species commonly used as green manure were under study: rattlepod (*Crotalaria breviflora*), pigeon pea (*Cajanus cajan*) and jack bean (*Canavalia ensiformis*) and they were cut during *C. adamantium* flowering. This strategy in AFS aims to increase biomass, protection, soil cover and available nitrogen. The study concluded that a wider spacing between individuals of *C. adamantium* and green manure promoted by *C. breviflora* together with *C. cajan* had a positive impact on the growth of *C. adamantium* and fruit yield (Gondim et al., 2021).

A project funded by the International Fund for Agricultural and Development (IFAD), the United States Department of Agriculture (USDA) and the Government of the Republic of Cameroon have worked directly with the local community to promote a multifunctional agriculture which could empower smallholder farmers to help them-selves overcome poverty, hunger and social deprivation while creating more sustainable farming systems and breaking cycles of land degradation. The project integrates agriculture and agroforestry, marketing of agricultural and tree products, microfinance and post-harvest machinery and a self-help package for poor small-holder farmers based on capacity building, communication and community development. The integrated approach to rural development follows three step process: the restoration of soil fertility by using green manure, also called "fertilizer trees"; tree domestication aiming the development of tree crops to replace the lost resource of forest species and the enrichment and diversification of farmland, making it more productive and ecological functional; and promotion of local entrepreneurship through the development of value-adding and processing technology and increase of products' availability throughout the year. The promotion of native species' production chain and this multifunctional agriculture model has very low-tech appropriate technology and relies on non-governmental organizations, community-based organizations and researchers with a coordinating and mentoring role. Those characteristics makes the project and steps suitable and a model that can be implemented and followed in other underdeveloped and developing countries, such as Brazil (Asaah et al., 2011).

A study developed in the Peruvian Amazon had analyzed the economic potential of neglected and underutilized species (NUS) that is, crops that hold significant and known potential for improving diets and nutrition while protecting agrobiodiversity, but that are marginalized by the mainstream market. It also relies on traditional knowledge related to the local socio-economic reality. Ten different species were identified and projections of species revenue and profitability shows that NUS-based AFS can be profitable in the second year of implementation, soil and environment restoration and an increased crop yield, but farmers declared to have technical issues on cultivating and/or harvesting these native fruits (Lagneaux et al., 2021).

A comparative study assessed the genetic diversity of *C. adamantium* in seven different populations, four located in Mato Grosso do Sul, by analyzing microsatellite markers in the years 2011 and 2017. The authors observed a positive correlation between secondary vegetation and heterozygosity, i.e., genetic diversity, and a negative correlation between the presence of exposed soil and the inbreeding coefficient. In fact, in the last decades occurred an expansion of agriculture, exposed soil and pasturelands and a decrease in savanna fragments or secondary vegetation where the guavira populations were assessed. Areas with more secondary vegetation presented higher genetic diversity, which represents high adaptive potential of species concerning environmental changes, and a high inbreeding coefficient was observed with exposed soil nearby, which may indicate that pollination among individuals could have been affected by distance, intensification of agriculture and pesticide exposure. They concluded that a decreased gene flow in *C. adamantium* population and an increased inbreeding rate indicates environmental degradation influenced by land use and land cover (Crispim et al., 2021). Despite those finds, *C. adamantium* has an incredible recovery capacity after several days of drought and could, therefore, be used to restore degraded areas (Junglos et al., 2016).

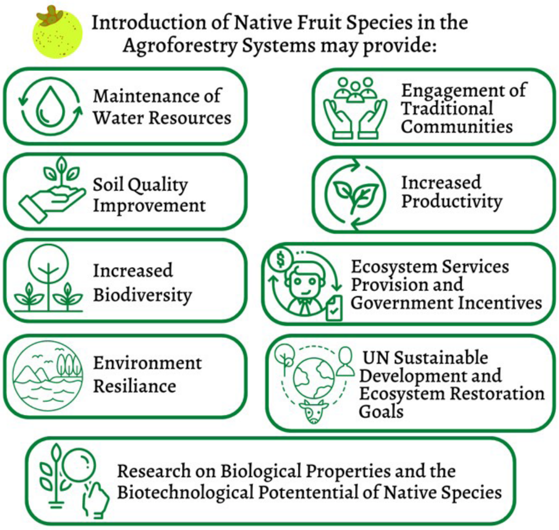

Figure 4. Potential benefits of the use of native fruit species for agroecological management and sustainable development based on UN Ecosystem Restoration Goals. Source: Elaborated by the author.

In addition, as native species, *C. adamantium* could also be used as an ecological buffer favoring established agricultural lands or livestock, converting conventional agriculture into restored ecosystems by intercropping and/or surrounding existing farm-lands. This approach could be better accepted by landowners who have already opted for cash crops and beef cattle, and, with parsimony, would ensure increased productivity and microclimate stability, thus providing ecosystem services and, consequently, tax benefits (Asaah et al., 2011; Foley et al., 2011; Benayas and Bullock, 2012; Huss et al., 2022). The potential benefits of using native fruit species, such as guavira for Cerrado, agroecological management and sustainable development are listed in Figure 4. Despite the extensive benefits observed and previously discussed, fruit tree-based AFS has its practical challenges such as species competition, *e.g.* nitrogen competition, impacting growth and/or productivity in the beginning of the AFS implementation and a higher investment and maintenance costs in the first few years until a stable production is stablished. For this, future fruit tree-based AFS should apply adaptative management such as considering the distance between individuals, pruning trees in competition zones, introducing high-value crops or biological nitrogen-fixing species to reduce competition and also be the subject of investment and government benefits (Do et al., 2020).

5. Conclusions and Future Perspectives

The indigenous people are allowed nowadays to collect guavira fruits under social and verbal deals with farmers and/or their heirs, however, without warrant of collection for the next fruitification season as had happened in the last one (Antonio, 2020). That is a reason to cultivate guavira. The investigations on guavira by-products benefits could promote environmental awareness and preservation of Cerrado and Pantanal biomes and sup-port agroforestry models of sustainable extractivism by family agriculture centers, respecting natural cycles and the culture of traditional peoples. Thus, *C. adamantium* could also be used as intercropping plantations and/or livestock already consolidated in the region.

Given this, further investigations on the potential for biotechnological products, production chain structuring and pilot studies using *C. adamantium* as an intercrop species are needed in a multidisciplinary context emphasizing the socio-environmental development of the Central-West region of Brazil together with stakeholders and government initiatives. The same approach and study are welcome and necessary in other regions and domains worldwide, with their native flora as means to a restorative end.

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