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REVIEW ARTICLE

Bibliometric review of achachairu (*Garcinia humilis*): a promising agent for health and future food applications

*Revisão bibliométrica do achachairu (*Garcinia humilis*): um agente promissor para a saúde e futuras aplicações em alimentos*

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Abstract

The achachairu (*Garcinia humilis* (Vahl) C.D. Adams) is a Bolivian fruit species that adapts well to tropical and sub-tropical climates and may feasibly be disseminated in other parts of the world. Data from the literature has revealed that both the plant and the fruit exhibited promising compounds for both nutritional and pharmacological purposes. This work aimed to review available publications involving the achachairu (*G. humilis*) through a bibliometric analysis using data from the Web of Science© (WOS) database. For greater precision and completeness in the research, the filters used included both the scientific nomenclature, and the popular name of the fruit, *G. humilis* and achachairu, respectively. The data-gathering stage yielded only 29 works containing the terms used in the search. Comprising 25 publications, Brazil was the country having the most records in the database, possibly because its climate is favorable for achachairu cultivation. Among the main research focus areas were attributes related to its chemical structure and pharmacological properties, particularly Guttiferone A, the compound responsible for the gastroprotective, antinociceptive and antiproliferative properties of its fruit, which occurs primarily in its seed. The peel also exhibited a bioactive and antioxidant composition. Thus, these two parts of the fruit, which are considered underutilized, due to the exclusive consumption of the fruit pulp, may have the potential for other purposes. Finally, considering the scarce scientific data regarding this matrix, which has a diversity of positive characteristics for the pharmacological and food industries, this bibliometric analysis revealed an opportunity for further research.

Keywords: Benzophenone; Guttiferone A; Seed; Antioxidants; Bioflavonoids.

Resumo

O achachairu (*Garcinia humilis*) é uma espécie frutífera boliviana, que apresenta boa adaptação em climas tropicais e subtropicais, podendo, portanto, ser cultivada em diferentes partes do mundo. Os dados da literatura revelam

que tanto a planta, em especial o fruto, apresentam compostos promissores para fins nutricionais e farmacológicos. Diante do exposto, o objetivo deste trabalho foi verificar as publicações disponíveis envolvendo o achachairu (*Garcinia humilis*), por meio de uma análise bibliométrica, utilizando informações da base de dados Web of Science© (WOS). Para uma maior precisão e abrangência na pesquisa, os filtros utilizados incluíram a nomenclatura científica e o nome popular da fruta, *Garcinia humilis* e achachairu, respectivamente. A etapa de coleta de dados resultou em apenas 29 trabalhos contendo os termos utilizados na busca. Com 25 publicações, o Brasil liderou os registros encontrados, possivelmente devido ao clima favorável do país para o cultivo do achachairu. Entre os principais focos de pesquisa, foram identificados atributos relacionados à estrutura química e às propriedades farmacológicas do fruto, em especial a Gutiferona A, um composto responsável por características gastroprotetoras, antinociceptivas e antiproliferativas, cuja ocorrência é principalmente na semente. A casca do fruto exibiu uma composição bioativa e antioxidante. Assim, verificou-se que essas duas partes do fruto, consideradas subutilizadas devido ao consumo exclusivo da polpa do fruto, podem ter potencial para outras finalidades. Por fim, diante dos escassos dados científicos sobre essa matriz, que possui uma diversidade de características positivas para as indústrias farmacêutica e alimentícia, a análise bibliométrica revelou uma oportunidade para novas pesquisas.

Palavras-chave: Benzofenona; Gutiferona A; Semente; Antioxidantes; Bioflavonóides.

Highlights

- Brazil is the leader in publications on the terms: *Garcinia humilis* and achachairu
- Guttiferone A stands out in the study focuses on *Garcinia humilis* and achachairu
- Achachairu seed and peel are promising sources as co-products

1 Introduction

Fruit consumption is gradually increasing, mainly as a result of greater awareness of the health benefits of ingesting it. However, the sensory characteristics of these products also contribute to their nutritional and therapeutic appeal (Ayala-Zavala et al., 2011; Silva et al., 2014). In view of these benefits, the consumption of fruits and vegetables is widely recommended to prevent non-communicable chronic illnesses such as type 2 diabetes, obesity, some types of cancer, metabolic syndrome, and cardiovascular inflammatory, as well as intestinal diseases, among others (Anderson & Waters, 2013; Habauzit & Morand, 2012; Kundu & Surh, 2013; Lever et al., 2014; Slavin & Lloyd, 2012).

Fruits generally exhibit large quantities of vitamins, mineral salts, and fibers. These components are responsible for providing health benefits related to a greater life expectancy, improved disposition, the prevention of pathologies and increased vitality. In fact, exotic fruits are an alternative for diversifying people's diet (Lorenzi & Lacerda, 2006).

Exotic fruit cultivation presents itself as an option for small producers to complement their family income, as well as a potential opportunity for research whose goal is to identify new business opportunities. However, to achieve popularity on the market, the fruit must exhibit properties that satisfy the palate of the general population, as well as quality characteristics related to the physicochemical parameters of the product (Lima et al., 2012). Against this backdrop, the achachairu, a fruit belonging to the *Garcinia* genus, *humilis* species, originally from Bolivia, stands out as a promising alternative due to its sensory characteristics (Nunes, 2004). Although it is native to Bolivia, the achachairu is widely cultivated in Brazil since it adapts easily to both tropical and sub-tropical climates, and records show that it has been cultivated in diverse regions of Brazil. However, details regarding the availability of its characteristics and properties are still scarce in the literature (Barbosa & Artioli, 2007; Soprano & Koller, 2008).

In its country of origin, the achachairu is greatly prized for its sensory characteristics; however, it is a seasonal product with a short harvest period, being available on the market only between the months of February and April. Despite its limited demand, plans currently exist to boost production in order to disseminate its applications for food industries. The goal of industrializing and exporting the fruit is to preserve the nutritional and antioxidant benefits of the *in natura* product, the form in which it is currently widely commercialized (Nunes, 2004; Instituto Boliviano de Comércio Exterior, 2010).

Scarce records appear in the literature regarding either the plant or the fruit. Among those studies that were found, Bagattoli et al. (2016) and Tomé et al. (2019) highlighted its nutritional and antioxidant potential, as well as the mineral load present in the fruit. Barros et al. (2017) identified bioactive compounds, whereas Terrazas et al. (2013) suggested that the fruit may perform diverse functions in the human body, such as healing, digestive and laxative activities, and may also fight rheumatism, gastric ulcers, and inflammation. In addition, both leaves and fruits exhibit several biflavonoid and benzene compounds with potential for immunotoxic, anti-inflammatory and anticancer activities (Cury et al., 2016).

Although the composition of the achachairu (*G. humilis*) exhibits favorable characteristics, studies involving the fruit are still scarce. The small amount of scientific research that has been conducted on the achachairu made possible a quantitative assessment of the records regarding the fruit. For this purpose, one of the approaches that makes it possible to track publication data, as well as information regarding the fields, regions and dates of studies that have already been conducted, is the bibliometric review based on a statistical analysis. According to Rodríguez-Rojas et al. (2019), the purpose of applying the method of bibliometric review is to extract results, identify authors, institutions, and journals in their respective areas of knowledge, for the purpose of serving as a guide or focus for subsequent publications, as well as to show tendencies for keywords submitted as part of the investigation.

In line with these purposes, this study aimed to conduct a bibliometric analysis to ascertain the information on the achachairu (*G. humilis*) currently available in the literature by tracing the data that has been published on this species, since there is not yet any collection of studies regarding this fruit, which is considered underexplored, despite the fact that promising studies have been published regarding its composition.

2 Characteristics and properties of the achachairu (G*arcinia humilis)*

The achachairu, known also by the names mangosteen, *tapacuarai*, *cachicheruqui*, *chachairu*, *tatairu*, Bolivian *bacupari*, shashairú, ibaguazú, cachicheruqui and apacuarai, belongs to the Clusiaceae family, *Garcinia* genus; however, its previous designation was *Rheedia*, and its species is *humilis*. The plant is originally from western Bolivia, a region containing a great variety of fruit species (Barbosa & Artioli, 2007; Instituto Boliviano de Comércio Exterior, 2010). The *Garcinia* genus includes approximately 600 species, both trees and bushes, of which the best known is the mangosteen (*G. mangostana L.*) (Duarte, 2011; Janick & Paull, 2008; Lorenzi & Lacerda, 2006).

Although the *G. humilis* is originally from Bolivia, the plant also grows in diverse regions of Brazil. The tree is non-deciduous, meaning that it retains its leaves throughout all seasons of the year; its height varies between 10 and 15 meters, and yellow latex is extracted from the trunk. It has coriaceous leaves that are glabrous and lustrous on the upper surface and whose length varies between 10 and 18 cm. Its flowers may occur alone or in groups, in both axillary fascicles, may be androgynous or hermaphroditic, and form between the months of July and September.

The term achachairu is a Guarani word meaning “honey kiss”. In Bolivia, although the fruit is quite popular and there is a significant commercial market for it, no records exist regarding industrialized production, since its consumption is being limited to its *in natura* state (Instituto Boliviano de Comércio Exterior, 2010).

The achachairu can grow in a variety of soils, thus making possible its cultivation in all types of regions, and easily adapts to mainly the tropical and sub-tropical climates. As a result, one of the countries that has

most broadly disseminated the fruit is Brazil, where the plant was introduced in the twentieth century and is currently found in the states of Minas Gerais, São Paulo, Pernambuco, Pará, Goiás and Santa Catarina. Despite the wide distribution of cultivation, the achahairu is not popular in the country and is sometimes confused with fruits of other species (Barbosa et al., 2008).

Its fruits (Figure 1) are drupes, have an average mass of 30 g and a rounded oblong shape, whose transverse and longitudinal dimensions are approximately 35.8 mm and 45.2 mm, respectively. Its peel is thick (average thickness of 3.53 mm), smooth, firm, and resistant, with an external coloration that may vary between yellow and orange, and an internal cream-straw color. The pulp, which does not adhere to the peel, is white and succulent, exhibiting a mucilaginous texture that oxidizes quickly and a sweet flavor of approximately 15 degrees Brix and a pH of 4.1. Each fruit usually has on average 3 seeds, two of which frequently remain underdeveloped and are unfit for germination; these are referred to as *chochas* (Janick & Paull, 2008). In relation to the total mass of the fruit, the peel represents around 52%, the pulp corresponds to ⅓, that is, 33% of the pulp, and the seed represents approximately 15% of the fruit.

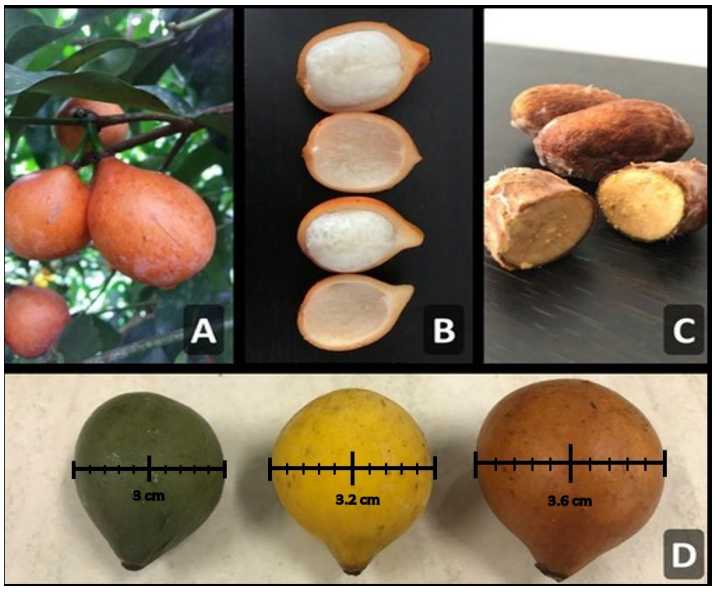

Figure 1. (A) Ripe achachairu on the tree; (B) Peel and pulp of achachairu; (C) Seeds of achachairu; (D) Achachairu at three ripening stages.

The development related to the maturation of the achachairu occurs between December and April, with the most significant transformations beginning in February. When they begin their development, the fruits are smaller, and their peels exhibit a green color. During the maturation process, the external color changes until it becomes reddish orange (Figure 1). During this period, natural reactions occur that cause the fruit to develop, the most important of which are a reduction in acidity, a gradual increase in sweetness and a softening of its structure. Its size also changes as a result of its growth. It is recommended that the mature fruit be harvested at the end of April, the time at which it reaches its maximum size and orange color. After being harvested, the fruits prove to be resistant upon being transported and conserve well under refrigeration (Barbosa et al., 2008). However, the achachairu is considered a non-climacteric fruit, that is, it exhibits low respiratory activity and a slight deterioration after harvesting, meaning that it is incapable of completing the maturation process after being harvested. Therefore, fruits must be harvested at their optimal point to be fit for consumption (Chitarra & Chitarra, 2005).

The achachairu is an easily cultivated fruit that shows great market potential due to its resilience upon being handled and transported, thus providing it with competitive advantages, in addition to exhibiting properties that are beneficial for health (Soprano & Koller, 2008).

3 Bibliometric review methodology

The bibliometric analysis was conducted during the month of February of 2022 according to the method described by Araújo et al. (2020); data were collected from the Main Collection of the Web of Science© (WOS) database. The filters used terms that describe both scientific nomenclature (*Garcinia humilis*) and the popular name of the fruit (achachairu). The purpose for including both search terms was to study all works related to the fruit with greater precision. Both searches were conducted in the section with the heading "topic," the category that includes data for titles, abstracts, keywords, and keywords plus. The data extracted included type of publication, geographical distribution, date and field of the studies, journals and institutions involved in the execution of the studies.

After collecting the information from the database, the data were correlated using the VOSviewer (Java version 1.8.0_261) software with the keywords of all identified studies involving *Garcinia humilis* and achachairu. To rank the results, the co-occurrence of keywords was established without regard to the strength of the link as described by the program.

4 Bibliometric analysis

The search of the database produced only 29 works related to the search terms, 24 of which were for the name achachairu, and 15 of which for the term *Garcinia humilis*, thus resulting in 10 works in which both terms were used.

Upon evaluating the publication categories, it was observed that 27 of the 29 documents obtained from the search were complete articles, while the remaining two publications were meeting abstracts.

4.1 Chronological and geographical information

The data collection observed that the first publications involving *G. humilis* and achachairu appeared in 2005, for which only one journal article was found, and remained scarce until the year 2008, for which another publication record was found. In 2011 and 2020 there were only two recorded publications each year, and the frequency of studies involving the fruit remained low, with three works being recorded annually for the years 2012, 2013, 2016, 2018 and 2019. The greatest number of publications occurred in the years 2017 and 2021, each of which it could be found four works published (Figure 2).

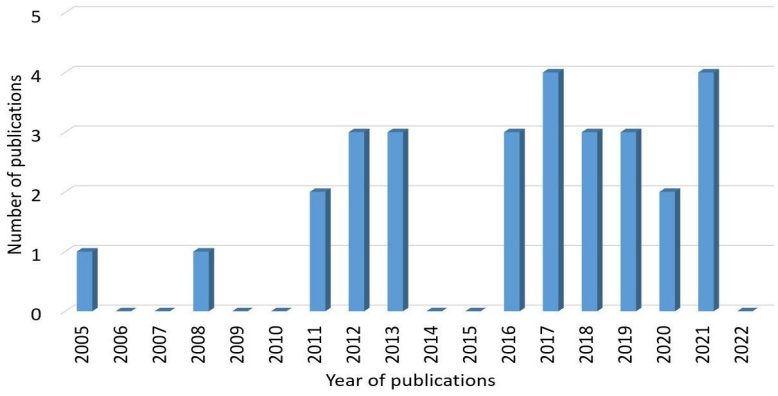

Figure 2. Number of publications per year related to the terms *Garcinia humilis* and achachairu.

Although records exist of studies involving the achachairu conducted on consecutive years, their volume remained low throughout the entire period under consideration, reaching a maximum of four publications per year that deal with the species.

The limited number of studies involving the achachairu may be a result of its being a seasonal product, as well as its lack of popularity in the scientific community. However, this lack of information represents opportunities for research on a little-known matrix that may have promising characteristics.

Although the achachairu is native to Bolivia, 27 of the 29 works identified were published in English, and the remaining two in Portuguese. According to the bibliometric analysis, Brazil had the greatest number of recorded studies, with a total of 25 works. The United States of America (USA) was the second, with a total of three publications, and the remaining countries listed had only one publication each (Table 1).

Table 1. Regions and main institutions with record of publications on the terms *Garcinia humilis* and achachairu.

Countries/Regions	Records*
Brazil	25
USA	3
Australia/ Bolivia/ Jamaica/ Mexico	1
Organizations	
University of Vale do Itajaí	12
Paulista State University	5
State University of Goiás	4
State University of Mato Grosso do Sul	3
Federal University of Goiás/ Federal University of Sergipe/ Federal Fluminense University	2

* Partnerships between institutions and/or countries imply coincident records, counting the numbers in duplicate.

Regarding geographical distribution, the records included authors and co-authors from various places, thus involving different research institutions. From the data collected, 32 organizations were identified that made publications with the terms *Garcinia humilis* and achachairu. Of these organizations, four had more than two publications (12, 5, 4 and 3), which were made by researchers from institutions located in several regions of Brazil, including the South (Santa Catarina), the Southwest (São Paulo) and the Center-East (Goiás and Mato Grosso do Sul) (Table 1). This observation confirmed the association of the fruit with a tropical climate, typical of Brazil, and the facility with which it may be cultivated.

4.2 Categories of publication and review of the main results

Concerning the field of study, the database search revealed 12 fields of publication involving the terms studied. The most prominent was the field of pharmacology pharmacy, which accounted for 10 publication records involving the terms *Garcinia humilis* and achachairu, followed by food science technology, for which 9 studies were recorded.

Among the other fields that were identified, agriculture represented a total of six works. Chemistry, integrative complementary medicine, plant sciences and toxicology had three publications each, while biochemistry molecular biology had two records each. In addition, four other fields, corresponding to immunology, medical laboratory technology, nutrition dietetics and science and technology - other topics, each have only one record in the database about the terms that were studied. Representing these fields of publication, 24 journals were identified. Of this total, only four journals (Abstracts of Papers of The American Chemical Society, Chemico Biological Interactions, LWT Food Science and Technology and Revista de Agricultura Neotropical) had more than one publication, each of which had two published works. However, the records from the Abstracts of Papers of The American Chemical Society had only meeting abstracts, unlike the remaining journals, which had complete articles. The remaining 20 journals identified in the database for the terms *Garcinia humilis* and achachairu had one publication each. By means of a study of the journals, it was possible to identify data regarding authorship, date, impact factor, focus of the study, the portion of the plant studied, and the number of quotations (Table 2).

Table 2. Authorship, impact factor, focus of the study, part of the fruit studied and number of citations of journals with publication records on *Garcinia humilis* and achachairu.

Journal	Authors	IF*	Focus of the study	Part studied	NC**
Abstracts of Papers of The American Chemical Society	Haase et al. (2011)	14.695	Xanthones and derivative of polyisoprenylated benzophenone	Whole fruit	0
Abstracts of Papers of The American Chemical Society	Haase (2011)	14.695	Polyisoprenylated benzophenone and chemopreventive xanthones	Whole fruit	0
Archives of Pharmacal Research	Dal Molin et al. (2012)	0.603	Chemical composition and the Guttiferone A	Seed	13
Biological Control	Haran et al. (2019)	1.598	Fruit flies and their associated parasitoids	Whole fruit	1
Chemico-Biological Interactions	Mariano et al. (2016)	2.754	Gastroprotective effect of xanthones	Branch	12
Chemico-Biological Interactions	Mariano et al. (2019)	2.754	1,3,5,6-tetrahydroxixanthone (THX)	Branch	5
Engenharia Agricola	Silva et al. (2018b)	2.773	Production of high-quality seedlings	Seedling	4
Evidence-Based Complementary and Alternative Medicine	Cechinel Filho et al. (2013)	1.648	Antiparasitic agents	Seed	22
Flavour and Fragrance Journal	Almeida et al. (2021)	3.782	Drying kinetics	Peel	0
Food Research International	Barros et al. (2017)	4.972	Bioactive compounds and the antioxidant activity	Seed, peel and pulp	24
Indian Journal of Pharmaceutical Sciences	Bagattoli et al. (2016)	0.721	Total phenol content and antioxidant activity	Whole fruit	8
Inflammopharmacology	Nunes et al. (2021)	3.238	Behavior of inflammatory cells and hypersensitivity	Leaf	2
International Journal of Food Science and Technology	Liu et al. (2017)	2.773	Production and purification of tannase	Seed	12
Journal of Aquatic Food Product Technology	Tomé et al. (2021)	1.020	Oxidative stability and bacteriological and sensory qualities	Peel	0
Journal of Ethnopharmacology	Marques et al. (2012)	3.690	Genotoxic and clastogenic effects	Seed	11
Journal of Food Measurement and Characterization	Tomé et al. (2019)	1.649	Nutritional value, total phenolic compounds, antioxidant potential and mineral profile	Peel, pulp and seed	2
Journal of Natural Products	Herath et al. (2005)	3.779	Polyisoprenylated benzophenone (guttiferone I)	Peel and stem	49
LWT-Food Science and Technology	Barros et al. (2019)	4.006	Microorganisms as producers of bioactive compounds	Whole fruit and its residues	2
LWT-Food Science and Technology	Ikeda et al. (2021)	4.006	Properties and composition of the seeds at three different maturation stages	Seed	1
Natural Product Communications	Melim et al. (2013)	0.468	Antibacterial activity	Aerial parts	2
Naunyn-Schmiedebergs Archives of Pharmacology	Niero et al. (2012)	2.050	Gastroprotective properties	Seed, leaf and branch	19
Nutrients	John et al. (2018)	4.777	Phytochemicals	Peel and pulp	6
Pesquisa Agropecuaria Brasileira	Virgolin et al. (2017)	0.644	Physical-chemical composition, bioactive compounds, and total antioxidant activity	Pulp	12
Pesquisa Agropecuaria Tropical	Silva et al. (2018a)	0.720	Formation of seedlings	Seedling	3
Pharmaceutical Biology	Mariano et al. (2015)	2.971	Chemical profile and xanthones	Branch	7
Plos One	Terrazas et al. (2013)	2.740	Benzophenone (guttiferone A)	Seed	15
Revista Brasileira de Fruticultura	Barbosa et al. (2008)	0.614	Seeds germination and seedling development	Seed	12
Revista de Agricultura Neotropical	Melo et al. (2017)	N.I.***	Physicochemical quality	Whole fruit	3
Revista de Agricultura Neotropical	Silva et al. (2021)	N.I.***	Seedling production	Seed	0

* IF: Impact factor. ** NC: Number of citations. ***N.I.: Not identified.

Although the publications have a significant impact factor, the number of quotations of the works is still low, with a maximum of 49 article references published in 2005 in the Journal of Natural Products. This detail reveals how little research has been conducted on the fruit and its species, since the total number of quotations was less than 50 over a period of 16 years.

Regarding the main research focus areas, a wide range of topics was observed (Table 2), including chemical characterization, bioactive and antioxidant composition, identification of antiparasitic agents, determination of phytochemicals, antimicrobial activity, enzymatic activity and protection against oxidation, germination properties, and genotoxic and clastogenic effects, among others. However, all studies highlighted the gastroprotective properties related to the benzophenone Guttiferone A.

Guttiferones are defined as polyprenylated benzophenones and are associated with various biological activities. They may exhibit free-radical scavenging activity, anti-ulcer effects, cytotoxicity, nitric oxide synthesis inhibition, chemoprevention of cancer, induction of apoptosis, anti-HIV activity and trypanocidal effects (Naldoni et al., 2009).

Various studies have shown that Guttiferona A in particular exhibits properties related to antioxidant capacity, confirmed by DPPH and ABTS tests (Acuña et al., 2010), a protective effect upon cells that have been damaged by iron sulfate, inhibition of lipid peroxidation, oxidative degradation of 2-deoxyribose (Figueredo et al., 2011), antioxidant activity and moderate antiplasmodial activity by means of *P. falciparum* (Ngouela et al., 2006), antimicrobial activity in fungi (*Trichophyton rubrum* and *Candida albicans*), bacteria (*Staphylococcus aureus* and *Escherichia coli*) and parasites (*Trypanosoma cruzi*, *T. brucei*, *Plasmodium falciparum*, *Leishmania infantum* and *L. amazonenses*), in addition to cytotoxicity in MRC-5 cells, belonging to the lineage present in lung cells (Monzote et al., 2011).

An examination of the group of studies identified using the search terms *Garcinia humilis* and achachairu revealed that Guttiferone A was the predominant compound identified in the seed of the fruit (Niero et al., 2012). The studies highlighted that the raw methanolic extract and the pure compound (Guttiferone A) exhibit a rich medicinal profile, showing antinociceptive and gastroprotective properties with antileishmanial and antimicrobial activities (Dal Molin et al., 2012; Cechinel-Filho et al., 2013; Melim et al., 2013), low genotoxicity (Marques et al., 2012), analgesic properties (Terrazas et al., 2013), effects against certain models of induced ulcers and reduction of gastric secretion (Niero et al., 2012), in addition to pronounced antiproliferative activity against cell lines, revealing potential anticancer activity (Mariano et al., 2015).

The data gathered from the published articles also revealed that 11 studies focused on the seed, six on the peel and six on the fruit as a whole.

John et al. (2018) reported in their studies that the peel of the achachairu, which is considered a food subproduct, exhibits potent cardioprotective properties in rats with metabolic syndromes induced by their diet. The peel also exhibited other favorable properties with nutritional applications, such as antioxidant activity, the presence of minerals (Tomé et al., 2019) and oxidative stability in meat products (Tomé et al., 2021).

In view of the above, it may be seen that the peel and seed of the achachairu, which are treated as waste products from the commercialization of the *in natura* fruit, in addition to exhibiting pharmacological properties that are beneficial to human health, also appear as potential co-products that should be investigated in order determine their nutrient content and functional capacity in the food industry.

Finally, among the studies that have been conducted on the fruit as a whole, Melo et al. (2017) related the parts of the plant to the chemical and physical conditions that are most adequate for harvesting the achachairu and indicated that the upper part of the calyx is the most ideal in terms of quality. The parameters used in the evaluation included the mass and diameter of the fruit, the mass of the seed, pH, total soluble solids (ºBrix), total titratable acidity and pulp yield.

Barros et al. (2019) detected endophytic strains of the genus *Candida*, which were responsible for the high quantities of phenolic compounds present in the achachairu, an observation that corroborated Bagattoli et al. (2016), whose study was promising in terms of the high total phenolic content in the fruit. These authors also highlighted the cytotoxic effect of the methanolic extracted from the seed, as well as the Guttiferona A presented in this extract, both of which inhibited the growth of tumor cells.

The available data points toward the need for more research regarding the composition of the achachairu in the search for technological innovations that may take advantage of the fruit's potential.

4.3 Correlation of keywords

Based on the co-occurrence of the keywords present in the bibliometric review, the authors were able to identify the tendency of the focus areas in the studies (Figure 3). To obtain these results, the option "all keywords" was selected in the Web of Science database. Upon analysis, the results were seen to cover the widest range of terms, including all keywords cited in the individual studies; the other options were "author keywords" and "keywords plus", whose search results yielded a smaller range of terms. According to Li (2018) and Rodríguez-Rojas et al. (2019), investigating keywords is an important bibliometric method due to the reference in the archive search, thus facilitating the consultation of the fields of study.

The filter applied in this analysis included keywords that were present a minimum of two times among the journals, yielding 29 combinations among the 205 keywords that were identified. The number of occurrences is shown in Figure 3 by means of circles that represent each keyword, whose size is proportional to its quantification, that is, a larger circle represents a greater number of occurrences of the keyword. The analysis revealed that the most prominent keyword was "seeds", which exhibited a close relationship to the words "biflavonoids", "extracts", "cytotoxicity" and "benzophenones", thus affirming the medicinal properties of this part of the fruit and confirming the data resulting from the analysis conducted for the publication categories. However, the terms that were observed to be directly related to "garcinia achachairu" and "achachairu" ("phenolic-compounds", "antioxidant", "bioactive compounds" and "natural antioxidant") referred to the antioxidant properties present in the species, maximizing the bioactive characteristics of the achachairu in publications that are focused primarily on applications in pharmacology.

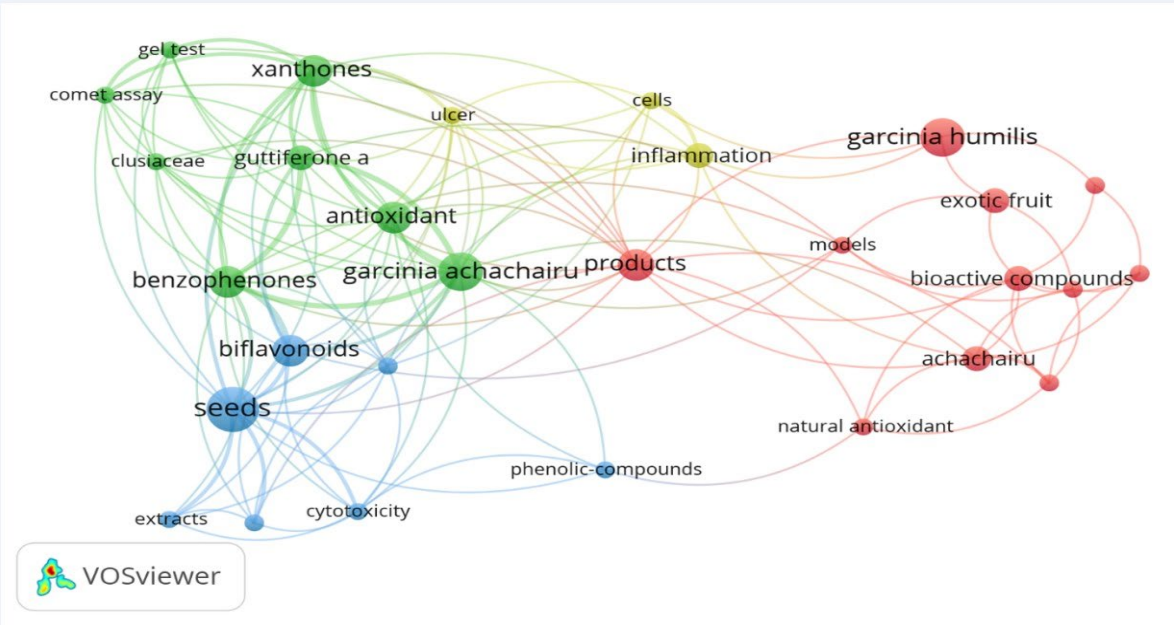

Figure 3. Co-occurrence analysis of keywords present in publications on the terms *Garcinia humilis* and achachairu.

5 Trends for future research on the achachairu

Studies suggest that the *Garcinia* species may perform diverse functions in the human body, such as healing, digestive and laxative activities, and may also fight rheumatism, gastric ulcers, and inflammation. In addition, both leaves and fruits exhibit several biflavonoid and benzene compounds with potential for immunotoxic, anti-inflammatory and anticancer activity (Cury et al., 2016). As has been shown, the presence of such benefits in the *Garcinia* genus, particularly in the achachairu, has awakened the interest of the pharmaceutical industry in research involving its main active compounds and potential to cure diseases. Their focus on the achachairu is mainly due to the compound known as Guttiferone A, which is present primarily in the extract from the seed of the fruit (Terrazas et al., 2013).

Guttifrerone A, which is obtained from achachairu seed extracts, has been shown to be a compound responsible for benefits such as gastroprotective effects (Niero et al., 2012), reduction in the ability to feel pain (Dal Molin et al., 2012) and clear antiproliferative activity (Mariano et al., 2015), among other properties. In this sense, there is a future opportunity for research on the potentiation of extraction, as well as the development of techniques for the purification of this compound. Another gap that can be explored in this context is the improvement of cultivars of the *humilis* species, focusing on the selection of Guttifrerone A.

The studies compiled in this review suggest that the achachairu (*G. humilis*) represents a promising prototype for obtaining agents with antinociceptive properties and a gastroprotective profile, in addition to anticancer activity. In this context, it was also verified that the use of the seed and peel of this fruit exhibits significant potential in the sector of new product development and applicability as new ingredients for the food industry. An example could be bioactive flour, with the ability to provide the food matrix with the benefits identified in these portions of the fruit.

5.1 Critical argument about the review

One of the deficiencies identified was the fact that the consumption of achachairu was limited to its *in natura* form. The lack of knowledge about the processes necessary for the conservation and transformation of the fruit limits its use in periods outside its seasonal availability. Therefore, we emphasize the need to implement technologies that allow the use of this fruit at times inverse to its production, such as simple freezing, allowing, in addition to the conservation of the whole fruit, the production of frozen pulp, providing opportunities for the development of technologies in production of flour from residues, as the peels and seeds of the achachairu are currently treated.

The conservation and application of technologies aimed at the pulp of this fruit can also contribute to a greater visibility of this portion, whose scientific records are minimal.

Finally, aiming to provide a healthy diet, rich in nutrients and medicinal agents, we reinforced the investment in the use of the peel and especially the seed in industrial processes in the food sector, especially in the application as a bioactive ingredient, enriching flour or even in the development of biodegradable films due to identified properties.

6 Conclusion

Upon conducting this bibliometric analysis based on the term achachairu and its respective scientific nomenclature, *Garcinia humilis*, 29 publications were found. This result revealed the low scientific visibility of the species, even though the fruit includes properties that are beneficial for the human organism in both a nutritional and medicinal sense. Therefore, this bibliometric review identified a remarkable opportunity for research involving the achachairu (*G. humilis*), since the use of this fruit is currently limited to consumption *in natura*.

In addition to providing an incentive for further research into the promising profile of the fruit regarding its antinociceptive, antiproliferative and gastroprotective properties, which are mainly observed in the seed, the resulting data also suggest that possible applications focus primarily on the field of food science, concerning the reutilization of waste products (peel and seeds) in order to promote the bioactive and antioxidant properties of the achachairu.

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