Eclética Química

Short review

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| Vol. 48 | n. 1 | 2023 |

Antioxidant property of secondary metabolites from *Garcinia* genus: A short review

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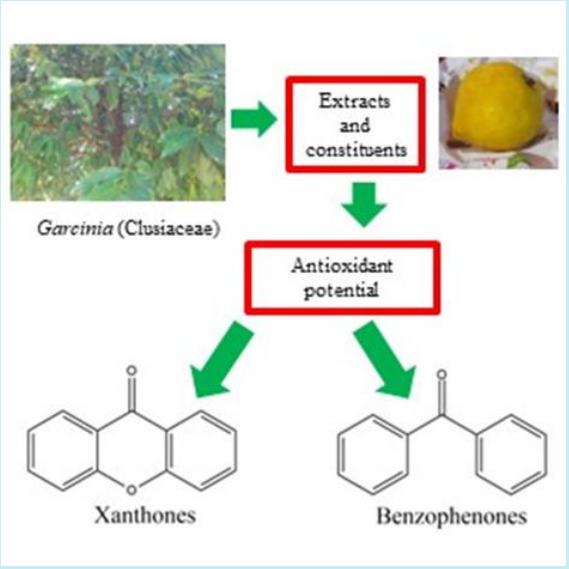
ARTICLE INFO

Article history:
Received: July 27, 2022
Accepted: December 5, 2022
Published: January 01, 2023

Section Editors: Assis Vicente Benedetti

Keywords:
1. Benzophenones
2. Mangosteen
3. Free radicals
4. Oxidative stress
5. Xanthones

ABSTRACT: Species from the *Garcinia* genus (Clusiaceae family) are used in the treatment of many diseases and metabolic disorders frequently associated with the oxidative stress. The characteristic metabolites found in this genus are xanthones and benzophenones, which have antioxidant properties, among relevant biological potentials. This review provides a specific vision about antioxidant activity of *Garcinia* species, reporting *in vitro* and *in vivo* assays, described from the last five years. The research about antioxidant properties of *Garcinia* species and their constituents can be directed in the development of new medicines and drugs.



CONTENTS

1. Introduction

The increase in consumption of ultra-processed foods and other modern habits harmful to health contribute to the growth in the number of people with chronic diseases such as diabetes, hypertension and obesity (Almarshad *et al.*, 2022). This situation leads to the requirement of research for alternatives in the treatment of these problems. Due to low cost and low side effects, natural products that have health benefits are the target of studies in order to develop remedies that act in this type of disease (A. Onaolapo and O. Onaolapo, 2020).

Species of the *Garcinia* genus (Clusiaceae family) are a relevant source of bioactive compounds. They are used in traditional medicine against problems frequently associated to oxidative stress, such as chronic ulcers, dysentery, diarrhea, gonorrhea, and diabetes (Aizat *et al.*, 2019a; Mello *et al.*, 2021). Approximately 450 species belong to this genus, and they are commonly found as trees, shrubs or subshrubs, occurring in Asia and some countries in Africa and South America (Mohamed and Ibrahim, 2020). A common feature among species of this genus is the production of yellow sap, occasionally white, in the endocarp of the fruit, bark and wood (Aizat *et al.*, 2019b; Inoue *et al.*, 2017; Machado *et al.*, 2017).

Several biological activities have been described for *Garcinia* species, including anticancer, anti-inflammatory, antimicrobial, antiviral, antidepressant, antioxidant, and neuroprotective activity against Alzheimer's disease. In addition, the antiobesity activity and appetite suppressant activity has been commercially explored through many supplements based on extracts of *Garcinia* spp. (Pandey *et al.*, 2017). This relevant and diversified biological potential is attributed to the xanthones and benzophenones, the most abundant classes of metabolites found in these plants (Do and Cho, 2020; Inoue *et al.*, 2017; Kurniawan *et al.*, 2021; Mello *et al.*, 2021; Wairata *et al.*, 2022; Wang *et al.*, 2017; Zafar *et al.*, 2019).

Garcinia mangostana, the most studied species, is popularly known as *mangosteen*. It is cultivated for its peculiar bittersweet taste and it is also known as the *queen of fruits* due to its sweet-sour taste and the wide range of medicinal benefits (Aizat *et al.*, 2019a). In traditional medicine, the pericarp of this species has been used to treat inflammation, ulcer, skin infection, amoebic dysentery, wound healing, and diarrhea (Wang *et al.*, 2017). *G. cochinchinensis* is similar in phenotype to *G. mangostana* and is called *yellow mangosteen* or *false mangosteen*, depending on the region of occurrence. In the young fruit stage, the *G. cochinchinensis* is confused with *G. mangostana*; the latter being typical of Southeast Asian countries such as Malaysia, Indonesia, Thailand and China. The tropical tree of *G. mangostana* can reach up to 25 m in height. The fruit in its mature stage is purple. In popular medicine, the pericarp has been used to treat inflammation, ulcer, and skin infection. In addition, several parts of *G. mangostana* are prepared by dissolving in water and after the fruit extract is commercialized as functional food and drink (Aizat *et al.*, 2019b; Wang *et al.*, 2017). *G. xanthochymus* is a perennial medium-size tree that can reach up to 20 m height and it is distributed in China, South East Asia and Western Gates of India. The *G. xanthochymus* fruit has a sub globose form, turns yellow when it is mature, and the seeds are embedded in yellow pulp. The fruits are eaten fresh or processed to make jams, vinegar, beverages and other food products. As well as other species of this genus, various subparts of the plant are used in the research like barks, leaves, seeds, stem bark and others (Hassan *et al.*, 2018; Prakash *et al.*, 2022).

In American countries there are some *Garcinia* species such as *G. brasiliensis* and *G. gardneriana*, which are used to treat inflammation, pain and urinary infections. These species are native to the Amazonian region; *G. brasiliensis*, for example is known as *bacuri*, *bacupari* or *bacuripari*. The fruit of *G. brasiliensis* is yellow and has a sour-sweet pulp. It has also anti-inflammatory, antinociceptive, antitumoral and antioxidant properties (Demenciano *et al.*, 2020; Espirito Santo *et al.*, 2020).

Species like *G. atroviridis*, *G. cola*, *G. cambogia* and *G. indica* are used to treat degenerative diseases, such as obesity, diabetes mellitus, and arthritis, as well as other metabolic syndromes (Kuswandi *et al.*, 2022). *G. cambogia* is used as an antiobesity supplement and can be effective in terms of weight loss (Andueza *et al.*, 2021; Han *et al.*, 2021). Andueza *et al.*, (2021) warn about the negative effect of *Garcinia* supplements for weight loss because it can be associated with liver damage and to lesser extent with serotonin toxicity.

The responsible compounds by antioxidant property in *Garcinia* species are phenolic compounds, flavonoids, phenolic acids, anthocyanins, xanthones and benzophenones, because there is relationship between free radical scavenging and total phenolic content and total flavonoids content (Espirito Santo *et al.*, 2020; Kainama *et al.*, 2020). Another important compound present in the genus *Garcinia* is hydroxycitric acid, which, together with hydroxylated xanthones and benzophenones, has a significant antioxidant activity. It controls the oxidative stress with hydroxycitric acid and others bioactive compounds from *Garcinia* regulating the concentration of reactive oxygen species, being one important therapeutic strategy (Han *et al.*, 2021).

Eclética Química, vol. 48, n. 1, 2023, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54

Bioactive compounds, such as phenolics compounds, flavonoids and biflavonoids, xanthones and benzophenones, found in this genus are strong antioxidants that complement and enhance the functions of vitamins and enzymes, protecting against oxidative stress (Mello *et al*., 2021). These compounds may be used in the food industry, mainly in meat products, in which oxidation is one of the main problems related to their deterioration (Beya *et al*., 2021). Another strong trend in the study of natural antioxidants is their use to preserve the quality of raw food, suggesting another possible application for plant extracts and isolated metabolites that show this property.

Based on the relevant potential of plants as a source of antioxidant compounds, the present review aims to describe the antioxidant property of species of the *Garcinia* genus, reported between 2017 and 2022.

2. Methodology

Data relating to *Garcinia* spp. and their antioxidant potential were obtained through PubMed and Google Scholar published in the last 5 years. The species of *Garcinia* shown here were chosen due to the number of publications such as *G. mangostana*, *G. kola*, *G. xanthochymus* and others. Another reason was the relation with metabolic disorders. The following exclusion criteria were adopted: 1- article whose full text was not accessible in the database; 2- publications that did not include the terms "*Garcinia*" and "antioxidant activity" search phrases in the abstract or title; 3- articles which are not written in English; and 4- articles in which the phytochemicals used in the biological activity assays were not isolated from these species but were acquired from industries. The chemical structures of compounds mentioned in this text were drawn using ChemDrawn 12.0 software.

3. An overview about oxidative stress and free radicals

The terms oxidants or pro-oxidants are related to the reactive oxygen species (ROS) and reactive nitrogen species (RNS). Both of them can be described as free radicals, although ROS can be found as non-free radical species. Free radicals are atoms or molecules containing one or more unpaired electrons in the valence shell (Elmund and Hartrianti, 2020). Because of its odd and unpaired electron, the radical becomes unstable, short-lived, and reactive. Due to their high reactivity, radicals interacts with other substances to remove their electrons and achieve stability. The substance that has suffered the electron remotion can turn into a radical and reacts with a subsequent one and, thus, start a chain reaction, which ultimately causes cellular damage (Kumar *et al*., 2021; Omidifar *et al*., 2021). These free radicals can be generated in normal mitochondrial processes. This phenomenon, oxidative stress, occurs when pro-oxidant substances are in higher concentration than antioxidant substances. Then, they may cause oxidative damage due to the absence of antioxidant defense. The examples for the radicals include superoxide ($O_2^{\bullet-}$), oxygen radical ($O_2^{\bullet\bullet}$), hydroxyl (OH•), alkoxy radical (RO•), Peroxyl radical (ROO•), Nitric oxide (NO•) and nitrogen dioxide ($NO_2^{\bullet}$) (Abubakar *et al*., 2020; Kumar *et al*., 2021).

When the number of oxidizing substances, whether free radicals or nonradical reactive species, are at a higher level, the body is able to neutralize by the action of antioxidant substances and, by the enzymatic antioxidant system, the phenomenon oxidative stress occurs. This phenomenon describes the level and state of oxidative damage to tissues and cells caused by ROS and other radicals. Oxidative stress can be defined as an imbalance between concentration of free radical and other oxidative compounds and the decrease of concentration of antioxidants, which lead to a disruption of redox signaling, control and molecular damage (Cassidy *et al*., 2020; Kumar *et al*., 2021; Mohamed and Ibrahim, 2020). In mental illness, for example, the concentration of antioxidants and their markers can indicate the level of oxidative damage and suggest the presence of a particular disease or disorder. In this context, the reduction in the level of antioxidants such as glutathione, glutathione transferase and catalase, as well as the increase in ROS and RNS and the variability of their concentrations, may indicate differences in the initial and final stages of healthy problems related to this balance (Ashton *et al*., 2019).

In order to control the undesired action of radicals, the search for compounds that perform this function is increasing. In this case, these substances are called antioxidants. They can be present in the body and convert radicals and other reactive species into stable species. Antioxidants act by different mechanisms of action, including radical scavengers, singlet oxygen inhibitors, peroxide inactivators and metal chelators (Gulcin, 2020). Redox markers are also used as evaluation parameters for oxidative stress, there is an increase in malondialdehyde and thiobarbituric acid reactive substances markers. The antioxidant enzymes themselves can be used as markers that are altered in the context of serious diseases, such as superoxide dismutase, catalase and glutathione peroxidase, as they indicate the active level of the body's antioxidant defense. High levels of oxidative stress may originate in the mitochondria and are associated with

Eclética Química, vol. 48, n. 1, 2023, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54

their dysfunction or, in part, when the oxidative damage to the mitochondria happens (Ashton *et al*., 2019).

A variety of assays are used to evaluate antioxidant property of secondary metabolites from plants, by different mechanisms. Among them, it is possible to cite assays of radical capture activity or reactive species, reducing power and metal chelation. The most common methods for evaluating antioxidant activity to be used is the radical scavenging activity assay of 2,2-diphenyl-1-picrylhydrazyl (DPPH), radical 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), ferric reducing antioxidant power (FRAP) and metal chelation capacity (Wairata *et al*., 2022). Depending on the reagents involved, the type of antioxidant and oxidant reactions can occur in two distinct mechanisms in order to convert the radical into a stable species. Both mechanisms lead to the same results (Gulcin, 2020). So, the basis of the chemical reactions involved is categorized into hydrogen atoms transfer (HAT) and single electron transfer (SET). HAT (Eqs. 1 and 2) is defined as one H atom is transferred to a radical target resulting in a stable product and SET (Eqs. 3–6) as one or more electrons are transferred to reduce target free radicals.

$$ROO^{\bullet} + AH/PheOH \rightarrow ROOH + A^{\bullet}/Phe\text{-}O^{\bullet} \quad (1)$$
$$ROO^{\bullet} + A^{\bullet} \rightarrow ROOA \quad (2)$$
$$ROO^{\bullet} + AH/PheOH \rightarrow ROO^{-} + AH^{+}/PheOH^{+} \quad (3)$$
$$ROO^{-} + AH^{+}/PheOH^{+} + H_2O \rightarrow A^{\bullet}/Phe\text{-}O^{\bullet} + H_3O^{+} \quad (4)$$
$$ROO^{-} + H_3O^{+} \rightarrow ROOH + H_2O \quad (5)$$
$$M(III) + AH/ArOH \rightarrow AH^{+}/ArOH^{+} + M(II) \quad (6)$$

Reactions HAT and SET, where AH = any antioxidant with donatable H or electron, PheOH = phenol or polyphenol antioxidants, M = redox metal. Reactions based in SET involve one redox reaction with the antioxidant compound.

Antioxidant assays like DPPH, ABTS and FRAP occur by SET mechanisms. The DPPH radical capture assay is among the most used assays in the evaluation of antioxidant activity (Benzie and Devaki, 2017; Sethi *et al*., 2020). DPPH is a stable radical of purple color and soluble in ethanol. After reacting with antioxidants, electrons or hydrogen atoms, it loses its purple color, becoming colorless or slightly yellowish. The colorless compound formed is also called 2,2-diphenyl-picrylhydrazyl or reduced DPPH (Gulcin, 2020).

The $ABTS^{\bullet+}$ radical is prepared from nonradical ABTS by reacting with a strong oxidizing agent, such as persulfate ion (Sethi *et al*., 2020). $ABTS^{\bullet+}$ is a bluish green cation radical with maximum absorption at 734 nm, which gradually loses its color intensity when it reacts with antioxidant species (AH, Ar-OH) (Gulcin, 2020).

The FRAP of extracts from plant samples occurs through single electron transfer reactions. This is a method that measures the ability of the potential antioxidant to transfer an electron to reduce any compound, in this case the transition metal iron, as well as carbonyls and other oxidizing radicals (Benzie and Devaki, 2017; Sethi *et al*., 2020). The need to investigate the ability to reduce iron ions in their involvement in the oxidative process, increasing the concentration of ROS, consequently, aggravating the oxidative stress. Iron participates in the Fenton reaction, present in the body (Benzie and Devaki, 2017). Some ROS are moderately reactive such as superoxide ($O_2^{\bullet-}$) like most biological molecules. However, through the Haber–Weiss reaction catalyzed by the Fenton reaction, other extremely reactive ROS are generated (Gulcin, 2020). Fe^{3+} reacts with the superoxide to form Fe^{2+} (Eq. 7). This cation reacts rapidly with hydrogen peroxide (H_2O_2) producing ion of iron III, radical hydroxyl and the hydroxyl ion (Eq. 8), ROS that are extremely harmful to the body (Benzie and Devaki, 2017; Lakey-Beitia *et al*., 2021). The combination of Eqs. 7 and 8 results in the iron-catalyzed Haber–Weiss reaction (Eq. 9), which turns out to be possible *in vivo* (Engwa, 2018).

$$Fe^{3+} + O_2^{\bullet-} \rightarrow Fe^{2+} + O_2 \quad (7)$$
$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^{-} + HO^{\bullet} \quad \text{Fenton reaction} \quad (8)$$
$$O_2^{\bullet-} + H_2O_2 \rightarrow O_2 + HO^{\bullet} + OH^{-} \quad \text{Haber–Weiss reaction} \quad (9)$$

The importance of evaluating FRAP is in reducing of the Fe^{3+} in Eq. 7, as this prevents the formation of ROS, whereas in chelation of iron, the antioxidant compounds present in the extracts chelate the ion Fe^{2+} in Eq. 8, also preventing the formation of ROS. In general, the chelation capacity of metals is determined by measuring the chelating effect of antioxidants for iron ions, Fe^{2+} (Gulcin and Alwasel, 2022). The chelating capacity of antioxidant compounds can be measured to chelate both Fe and Cu, and in turn, phenolic and flavonoid species are both able to chelate these transition metals (Lakey-Beitia *et al*., 2021). The chelation of transition metals prevents them from participating in reactions that generate oxidant species, for example, in Fenton and Haber–Weiss reactions generating ROS (García-Diez *et al*., 2021).

4. Chemical constituents of *Garcinia* genus

The major classes of secondary metabolites found in species from *Garcinia* genus are phenolics compounds, flavonoids, biflavonoids, xanthones, benzophenones and

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ISSN: 1678-4618
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terpenes (Hassan *et al*., 2018). These phytochemicals can be isolated by different parts of the plant, using different techniques, such as conventional fractionated extraction, ultrasound assisted extraction and microwave assisted extraction (Carrillo-Hormaza *et al*., 2020; Chang *et al*., 2020; Ramirez *et al*., 2019).

The two main classes of bioactive compounds found in species of the genus *Garcinia* are xanthones and benzophenones, associated with isoprenyl groups and glycosides. The base skeleton of xanthone is composed of two benzene rings linked by a γ-pyran ring, and its tricycle structure can be associated with its biological activities (Ashton *et al*., 2019; Zafar *et al*., 2019). The name *xanthone* comes from Greek language, where *xanthos* means yellow color, because xanthones are commonly obtained as yellow solids (Kurniawan *et al*., 2021). Xanthones can be found in various parts of plants from the *Garcinia* genus, such as the fruit, peel of the fruit, bark, and seeds (Mohamed and Ibrahim, 2020). The biosynthesis of xanthones is given based on the numbering of ring A and B from xanthones. The biosynthesis pathway of ring A (carbon 1-4) comes from the acetate pathway, while the ring B (carbon 5-8) is given by the shikimic acid pathway (Pinto *et al*., 2021). Several xanthones analogs and their glycosides are obtained by adding substituents to the side chain of the aromatic rings of the skeleton base, but in different positions. Thus, there are reported hydroxylated xanthones, from mono to polyhydroxylated, prenylated, alkylated, linked to charged groups, linked to glycoside groups, linked to alkoxide groups and xanthones found in the form of dimers and trimers (Zafar *et al*., 2019).

The xanthones found in *Garcinia* species exhibit important diverse biological properties, such as antioxidant, antitumor, antiviral, anti-HIV, antiglycemic, antimicrobial and neuroprotective activities such as in Alzheimer's disease, Parkinson's disease and depression, anticancer (Do and Cho, 2020; Inoue *et al*., 2017; Kurniawan *et al*., 2021; Wairata *et al*., 2022; Wang *et al*., 2017; Zafar *et al*., 2019).

The xanthones isolated from *Garcinia* species exhibit important diverse biological properties, such as antioxidant, antitumor, antiviral, anti-HIV, antiglycemic, antimicrobial and neuroprotective activities (Kurniawan *et al*., 2021; Wairata *et al*., 2022; Wang *et al*., 2017). Examples of these metabolites include α-mangostin, β-mangostin, γ-mangostin, gartanin, 8-desoxygartanin, garcinexanthone A, cabalaxanthone, garcixanthone A, garcinone C, lichexanthone, subelliptenone H, 12b-hydroxy-des-D-garcigerrin A, garciniaxanthone B, garcigerin A, garcinone-E, smeathxanthone A, and 1,3,5-tridroxyxanthone (Fig. 1) (Kusmayadi *et al*., 2019; Wairata *et al*., 2022; Zafar *et al*., 2019).

Benzophenones are a class of compounds similar to xanthones. However, there is no oxygen present between the two aromatic rings. The base form for benzophenones is characterized by phenol-carbonyl-phenol (Inoue *et al*., 2017; Murthy *et al*., 2020). They can also be in the form of polyisoprenylated, linked to glycosides and other substituents, as well as xanthones. Examples of known benzophenones are isogarcinol, garcinol and 7-epiclusianone, xanthochymol, 2,4,6,3',4',6'hexahydroxybenzophenone.

Morelloflavone and volkensiflavone are biflavonoid found in *G. brasiliensis* (Fig. 2) (Moreira *et al*., 2017; Pasaribu *et al*., 2021b). The A ring of benzophenones usually have one or two substituents present. On the other hand, the B ring can undergo prenylation and cyclization, producing a variety of different compounds. The benzophenones can be unique with bi-, tri- and tetracyclic ring systems and show different biological activities, such as antioxidant, antimicrobial, anti-HIV, cytotoxic, hepatoprotective, antiparasitic, and antidiabetic. Benzophenones are the main intermediates in the biosynthetic pathway of xanthones (Inoue *et al*., 2017).

Eclética Química, vol. 48, n. 1, 2023, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54

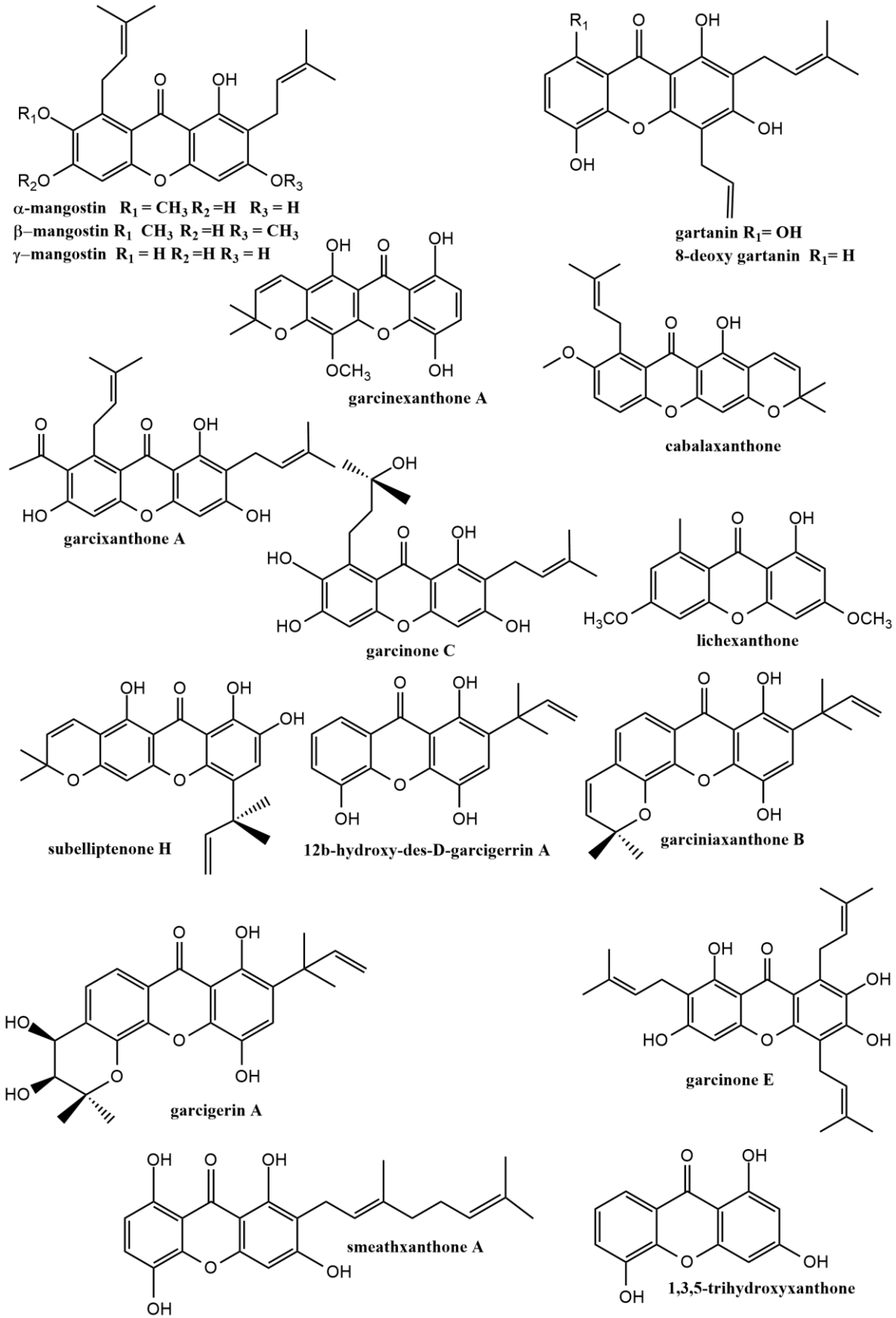

Figure 1. Examples of xanthones found in the *Garcinia* species.

Eclética Química, vol. 48, n. 1, 2023, 41-54
ISSN: 1678-4618
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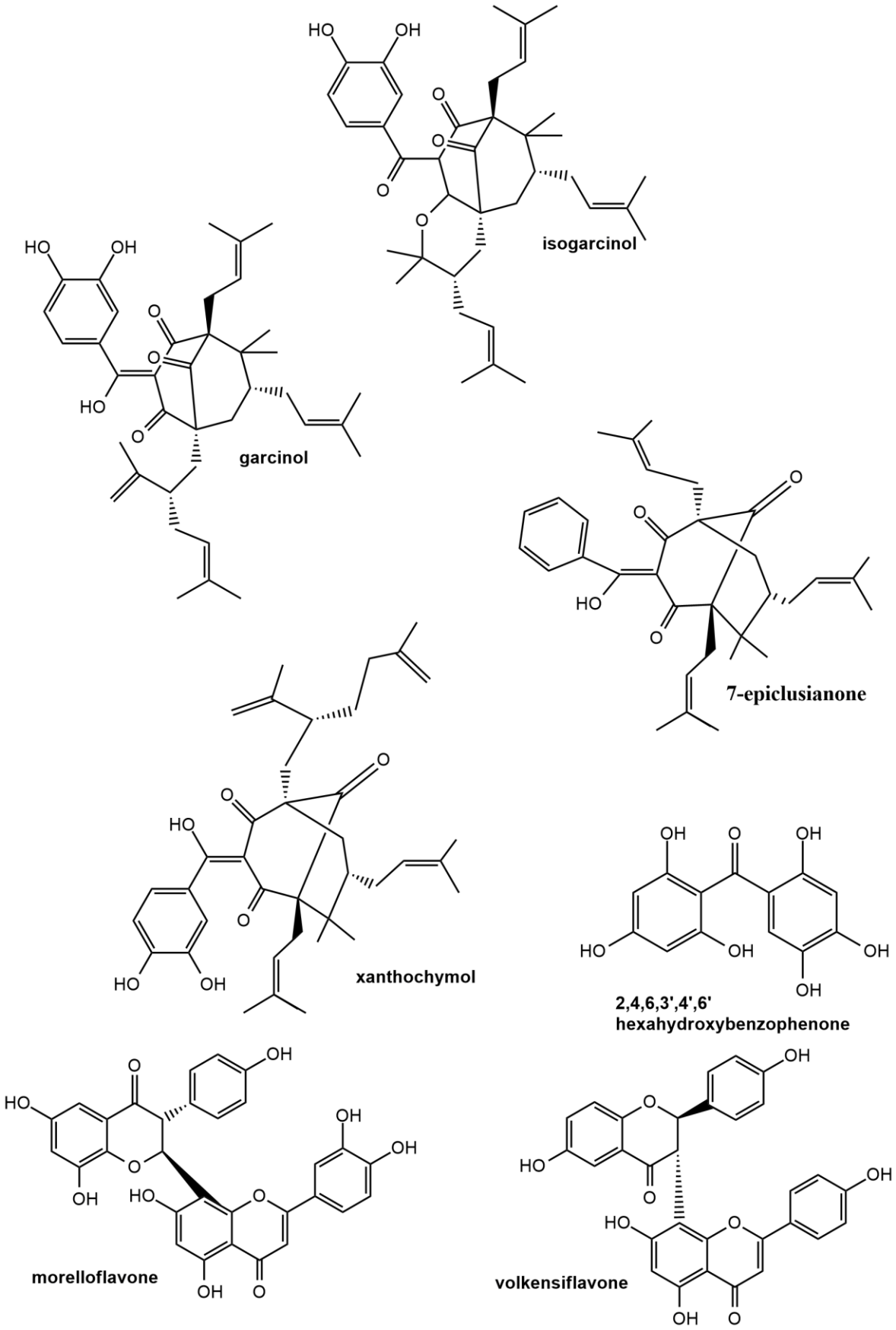

Figure 2. Examples of benzophenones and flavonoids presents in *Garcinia* species.

Eclética Química Journal, vol. 47, special issue 2, 2022, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54

5. Antioxidant activity of extracts and metabolites of *Garcinia* genus

Xanthones and benzophenones can be classified as primary antioxidants because they are capable of donating hydrogen or electrons to ROS. In consequence, they delay, inhibit or prevent the initiation step or interrupt reaction in the chain. Xanthones react with free radicals through electron transfer or hydrogen atom transfer. The antioxidant activity of phenolics compounds may vary according to the amount of hydroxyl substituents and the position of other substituents in the skeleton (Gulumian *et al.*, 2018). This happens because hydroxyl groups attached to aromatic rings, forming phenolic groups, act effectively to capture free radicals. The number of hydroxyl groups present in xanthones, flavonoids and other classes of compounds also affects their antioxidant potential. Although dihydroxy and trihydroxy xanthones or flavonoids have significant antioxidant activity, tetrahydroxy xanthones or flavonoids have higher values than di- and trisubstituted. However, it is necessary to take into account the presence of other substituents that alter the interaction between the xanthone and the oxidizing compound. Among these substituents it can be listed alkoxide, prenyl groups. In addition, several natural xanthones that have antioxidant property also exhibit other activities and the scientific community has developed studies to evaluate the structure-activity relationship to better investigate the biological potential of these molecules (Gulcin, 2020; Gulumian *et al.*, 2018; Zafar *et al.*, 2019)

Virgolin *et al.* (2017) investigated the antioxidant activity by FRAP assay of extracts of the fruits of *G. humilis* and *G. xanthochymus* using 70% acetone. It was observed a good potential for these samples, 2995.88 ± 3.23 and 489.39 ± 0.48 µmol trolox 100 g^{-1} pulp, respectively.

Considering the evaluation of isolated compounds from the *Garcinia* genus, Wairata *et al.* (2021) investigated the antioxidant, antidiabetic and antiplasmodial properties of xanthones from *G. forbesii*. From the stem bark of *G. forbesii*, it was isolated five xanthones: lichexanthone, subelliptenone H, 12b-hydroxy-des-D-garcigerrin A, garciniaxanthone B and garcigerin A (Fig. 2). These authors evaluated the antioxidant property of the compounds described by scavenging DPPH, ABTS, and FRAP methods, and verified that those metabolites showed strong antioxidant activity by those methods. The most effective compounds were garciniaxanthone B for DPPH assay and 12b-hydroxy-des-D-garcigerrin A for ABTS assay. The antioxidant activity of these compounds can be explained by the presence of hydroxyl groups linked in aromatic rings, which react with radical DPPH through the SET mechanism. From *G. brasiliensis*, fukugetin, 7-epiclusianone and guttiferone-A were found in its fruits and seeds. These compounds performed relevant antioxidant activity (Melo *et al.*, 2021).

Considering the chelation of metals, Chew and Lim (2018) evaluated the FRAP of *G. mangostana*, *G. atroviridis* and *G. hombroniana* extracts from leaves, pulps and pericarps of these species. Considering leaves and pulp extracts, *G. hombroniana* was more effective in chelating power (60% and 30%, respectively). The pericarp extract of *G. mangostana* showed more activity (78%) than *G. hombroniana* and *G. atroviridis* (45% and 11%, respectively). The parts of the same *Garcinia* species were compared in terms of antioxidant activity and total phenolic content and total flavonoids content.

Nguyen *et al.* (2021) evaluated the antioxidant activity of *G. fusca*, *G. hopii*, *G. planchonii*, *G. nigrolineata*, *G. gaudichaudii*, *and G. tinctoria*. The extracts were obtained with hexane, ethyl acetate and methanol in solid-liquid extraction. The antioxidant activity methods used were DPPH assay, hydroxyl radical scavenging and total antioxidant capacity. The higher values of IC_{50} for the DPPH assay were found in ethyl acetate extract and methanolic extract in all *Garcinia species*. For hydroxyl radical scavenging capacity, the strongest antioxidant activity is shown in ethyl acetate extract of *G. tinctoria* with 83.5% at IC_{50} of 1.5 µg mL^{-1}. About the total antioxidant capacity assay, the extracts obtained from *G. tinctoria* have the highest values 265.

Ramirez *et al.* (2019) evaluated the antioxidant activity by DPPH, ABTS and FRAP assays of seeds, epicarp and leaves of *G. madruno*. A sequential extraction of these parts with hexane, dichloromethane, ethyl acetate and methanol were done. The ethyl acetate fraction from leaves was more effective in the three assays. Research like this makes possible discussions and analysis between fractions of the same plant part and between all parts studied. The different polarity of solvent used influences directly the yield of antioxidant compounds and the IC_{50} value of antioxidant activity, solvents such as ethyl acetate, dichloromethane and others with medium polarity are good to extract phenolics compounds. Other articles are shown in Table 1.

Eclética Química Journal, vol. 47, special issue 2, 2022, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54

Table 1. Antioxidant property of *Garcinia* species.

***Species* (part of plant)**	**Compounds or extracts assayed**	**Assay for determination of antioxidant activity**	**References**
G. cochinchinensis (pulp and leaves)	Acetone extract	DPPH	Machado *et al.* (2017)
G. morella (tree's latex)	Acetone extract	DPPH, TAC, hydrogen peroxide scavenging activity (H_2O_2) and FRAP	Murthy *et al.* (2017)
G. morella (fruit)	Methanol extract	DPPH and FRAP	Choudhury *et al.* (2018)
G. mangostana (fruit peels)	Extraction with ethanol, acetone, ethyl acetate, methanol, hexane, acetic acid and distilled water	DPPH	Kusmayadi *et al.* (2019)
G. mangostana (pericarps)	α-mangosteen and γ-mangosteen	Determination of intracellular ROS, DPPH, lipid peroxidation	Lee *et al.* (2019)
G. brasiliensis (leaves, barks and seeds)	Ethanolic and aqueous extract	DPPH	Naves *et al.* (2019)
G. mangostana (pectin from rind)	Aqueous extract acidified at pH 2	DPPH	Wathoni *et al.* (2019)
G. gardneriana (fruits and leaves)	extracts of sequential extraction (ethanol, hexane, chloroform, ethyl acetate and hydromethanol fraction)	DPPH	Demenciano *et al*. (2020)
G. kola (leaves, roots and stem bark)	Hydro-ethanolic and methanol extract	DPPH, ABTS and FRAP	Djague *et al.* (2020)
G. mangostana (fruit)	Methanol extract	DPPH and FRAP	Abeysuriya *et al*. (2020)
G. mangostana (pericarp)	Isolated compounds: 2,4,6,3`,4`,6`-hexa hydroxybenzophenone; 6-O-β-D-glucopyranosyl-2,4,6,3`,4`,6`-hexa hydroxybenzophenone and 2R,3R-5,7-dihydroxy-8-C-β-D-glucopyranosyl-4`-methoxy-2,3-dihydroflavon-3-ol	DPPH	Mohamed and Ibrahim (2020)
G. lasoar (stem bark)	Extracts obtained by ethanol, ethyl acetate, dichloromethane and n-hexane; Petroleum ether; Extract obtained by aqueous infusion and other with methanol by maceration;	DPPH and ABTS	Kainama *et al.* (2020)
G. mangostana (pericarp)	Ultrasonic assisted extraction	DPPH	Sungpud *et al.* (2020)
G. latifolia (dried fruits)	Methanol fruit extract	DPPH	Reddy *et al.* (2021)
G. macrophylla (stem bark)	Macrophylloflavone isolated from ethyl acetate fraction	DPPH	Cane *et al.* (2020)
G. pedunculata (fruit)	Dry extract	DPPH	Hossain *et al.* (2021)
G. celebica (root bark)	Extracts (n-hexane, dichloromethane, ethyl acetate and methanol); (-)-cycloxanthochymol, isoxanthochymol and xanthochymol.	DPPH, ABTS and FRAP	Pasaribu *et al.* (2021b)
G. mangostana (pericarp)	Methanol extract	DPPH	Pasaribu *et al.* (2021a)
G. kola and *G. afzelii* (stem and bark)	Methanol extract (70%)	DPPH, ABTS and FRAP	Essuman *et al.* (2021)
G. xanthochymus (peel, pulp, rind and seeds)	Methanol extract of lyophilized peel; Methanol extract of lyophilized pulp; Ethanol extract of sun-dried rind; Methanol extract of sun-dried seed	DPPH, ABTS and FRAP	Prakash *et al.* (2022)

FRAP = ferric reducing antioxidant power; TAC = total antioxidant activity; DPPH = 2,2-diphenyl-1-picrylhydrazyl scavenging assay; ABTS = 2,2'-azinobis-(3-ethylbenzothiazoline-6-sulphonate) radical scavenging assay.

Eclética Química Journal, vol. 47, special issue 2, 2022, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54

It is important to highlight that many researchers report the relationship between antioxidant activity with other biological activities or alternative methods of extraction. Between them, the research of Chang *et al.* (2020) was based on the effect of a concentrated mangosteen (*G. mangostana*) drink, MCD, in rats after long-term running exercise in order to investigate changes in the antioxidant system and lactate clearance. Since aerobic exercise can lead to significant fatigue, oxidative stress and muscle damage, the authors investigated the level of lactate clearance and the levels of endogenous antioxidants such as superoxide dismutase, glutathione peroxidase and catalase, in addition to blood glucose, cholesterol, triglycerides and muscle malondialdehyde levels. The levels of glutathione peroxidase and catalase increased with the ingestion of concentrated mangosteen drink and the supplementation of this drink also increased lactate clearance, contributing to a better physical recovery of rats after exhaustion from running exercise. MDA concentration also decreased with mangosteen drink supplementation compared to the control group; however, there was no decrease of malondialdehyde in muscle.

Araújo *et al.* (2019) performed *in vivo* tests in mice that were ingesting ethanolic extract of *G. brasiliensis* leaves daily to evaluate its antioxidant activity, modulation of the intestinal microbiota and anti-inflammatory activity. The ethanolic extract of the leaf contained the biflavonoid morelloflavone and the benzophenone 7-epiclusianone. They concluded that the extract was able to reduce oxidative stress, demonstrated by the increase in the amount of antioxidant enzymes. It inhibited the inflammatory process, modulated the intestinal microbiota, favoring beneficial bacteria and regulating lipid metabolism, which reduces obesity (Araújo *et al*., 2019). The ethyl acetate extract of the seeds e from *G. kola* was evaluated by Idris *et al.* (2020) for *in vivo* antioxidant, anti-inflammatory and antidiabetic activities. Biochemical markers related to these processes such as glutathione peroxidase levels, lipid peroxidation revealed by malondialdehyde levels and biochemical markers for antidiabetic activity were evaluated. The levels of glutathione found in the group administered with *G. kola* were near to the healthy group, but the highest value was found in the treated group with insulin. The malondialdehyde levels increased in the group treated with insulin and the *G. kola* extract group compared to diabetic control group. These results emphasize that *G. kola* extract is a candidate for therapeutic uses in diabetes and oxidative stress treatment (Idris *et al.*, 2020). Tjahjani, *et al.* (2019) demonstrated antioxidant and antimalarial activity of *G. mangostana*'s ethyl acetate fraction for *in vivo* models.

All these reports highlight the relevant scientific potential of species from the *Garcinia* genus and stimulate the search for new sources of antioxidant compounds.

6. Concluding remarks

Garcinia genus shows significant free radical scavenging and antioxidant potential by the presence of xanthones and benzophenones. The isolated compounds and extracts from these species have potential to be applied in pharmaceutical and food industries. This emphasizes the continuation of studies involving these plants, because they can lead to the discovering new possibilities of application of these natural resources, increasing their scientific value.

Authors' contribution

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Data availability statement

The data will be available upon request.

Funding

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES). Finance Code 2013/2998/2014.

Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). Grant No: 307546/2014.

Acknowledgments

Not applicable.

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Eclética Química, vol. 48, n. 1, 2023, 41-54
ISSN: 1678-4618
DOI: 10.26850/1678-4618eqj.v48.1.2023.p41-54