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Nutritional Benefits, Phytoconstituents, and Pharmacological Properties of *Garcinia* Fruits: A Review

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Abstract: Indigenous fruits like *Garcinia* have underexploited sources of bioactive compounds and nutrients. They are rich in vitamins, proteins, minerals, and carbohydrates. In traditional medicine, *Garcinia* fruits are used to treat wounds, ulcers, inflammation, jaundice, constipation, dysentery, piles, and dermatitis. The compiled data comprises published articles from 2014 to 2023 on databases such as Web of Science, PubMed, Scopus, Google Scholar, and ScienceDirect. Different phytochemicals (xanthones, benzophenones, flavonoids, anthocyanins, organic acids, fatty acids, and terpenoids) have been isolated and reported from the fruits. The bioactive compounds found in these fruits help in protecting the body against free radicals, allergies, bacteria, fungi, viruses, and hepatotoxicity. The species are, therefore, of great value to human health. However, many species are unexplored. Most studies have focused on a few species already on the market. More studies are required to isolate phytochemicals from different species to unlock additional biological activities and their mechanism. Furthermore, the mechanism of action of most bioactive compounds is unknown. The current review provides a comprehensive report on Garcinia fruits' nutritional, phytochemical, and pharmacological profile. It explores the potential application of their bioactive compounds for nutraceutical and therapeutic purposes.

Keywords: *Garcinia*; phytochemistry; bioactivity; pharmacology; nutraceutical.

1. Introduction

Indigenous fruits are good food sources with additional physiological advantages and well-being [1,2]. They can be used as alternatives to supply nutrients since they are drought and heat-stress tolerant [3]. They provide health benefits beyond their nutritional value due to the presence of phytoconstituents [4–6]. *Garcinia* species belonging to the Clusiaceae family are indigenous fruit trees that grow wildly. Some species are cultivated for their fruits, ornamental use, traditional medicine, and domestic purposes in India, Nepal, Australia, Guatemala, Cuba, Dominica, Ecuador, Gabon, Ghana, Honduras, Jamaica, Liberia, Myanmar, Philippines, Puerto Rico, Singapore, Sri Lanka, Thailand, United States of America, Vietnam, and Zanzibar [7–9].

The Clusiaceae family is a good source of secondary metabolites, such as benzophenones, coumarins, anthocyanins, flavonoids, xanthones, and triterpenes [10,11]. The family has over 300 potential sources of medicinal and nutraceutical phytochemical constituents [12]. The nutraceutical properties of *Garcinia* species are a product of their primary (proteins, vitamins, and organic acids) and secondary (xanthones, alkaloids, terpenes, phenols, and flavonoids) metabolites [13,14]. Overall, the medicinal properties of the fruits depend on secondary metabolites, namely, phenols and flavonoids [15]. The secondary metabolites have been associated with the biological activities of the species. A wide range of biological and pharmacological activities have been reported, including antimicrobial, antifungal, cytotoxicity, antibacterial, antioxidant, anticancer, anti-COVID-19, anti-obesity, anti-HIV, hepatoprotective, and anti-melanoma [5,6,16–18]. Nevertheless, most studies have focussed on a few species already on the market, and more scientific data is available on the non-fruit parts of the *Garcinia sp*. This review, therefore, provides insight into the phytochemical constituents and biological activities of *Garcinia* fruits for further research on their nutraceutical and pharmacological potential.

2. Materials and Methods

A comprehensive literature search was conducted to provide an overview of the knowledge and gaps in this field. The compiled data was obtained from databases (Web of Science, PubMed, Scopus, Google Scholar, and ScienceDirect) for articles published from 2014 to 2023. The literature search was done without author bias, and keywords were chosen. The chemical structures of the identified compounds in this review were drawn using ChemDraw 12.0 software.

3. Botanical Description

Garcinia spp. belongs to the Clusiaceae family [19]. They are widely and naturally distributed in Asia, Africa, New Caledonia, Polynesia, and Brazil [13,19]. *Garcinia* spp. grows naturally and wildly in forest areas and can be propagated by seeds. They are mainly evergreen dioecious trees or shrubs with yellow resin and branches modified into spines possessing simple, opposite, or nearly opposite, leathery leaves [11,20,21]. The plants in this genus are known by several names, which include *Garcinia*, monkey fruit, kokum, sap trees, and mangosteen [22]. There are approximately 450 species of *Garcinia* [11,23]. In Southeast Asia, there are 200 species, and 30 of them are reported to produce edible fruits [8,24]. However, most species are unexplored in different parts of the world. *Garcinia* spp. tolerates a wide range of soils (forests, stony hillsides, and woodlands) and can grow up to a height of 30 m, bearing acidic fruits (with 1 to 12 seeds) that are orange or yellow [25]. The fruits are fleshy to woody berries, 10 - 750 g in weight, and are mostly globose in shape [26].

4. Proximate Composition of *Garcinia* Species

Garcinia species are one of the underutilized indigenous fruits despite being rich in nutritional properties. The fruits can be consumed fresh, dried, or processed into juice, jam, and jellies [27,28]. They are good sources of minerals, carbohydrates, amino acids (proline, alanine, asparagine, arginine, cystine, glutamic, aspartic, and glycine), fiber, organic acids, fats, proteins, and vitamins [29–33]. The fruits also contain anti-nutritional compounds, which include tannins (0.2-7.96 µg/g), saponins (5.12-9.06 mg/g), alkaloids (1.56-10 mg/kg), phytate (1.64-2.47 mg/g), and oxalate (1.26 mg/g) [30,31]. The nutritional composition of various *Garcinia sp*. is presented in Tables 1 and 2.

Table 1. Nutritional composition of *Garcinia* fruits [14,33–36].

Garcinia species	**Proteins (g/100 g)**	**Fat (g/100 g)**	**Carbohydrates (g/100 g)**	**Vitamin B12 (μg/100 g)**	**Thiamine (B1) (μg/100 g)**	**Riboflavin (B2) (μg/100 g)**	**Ascorbic acid (mg/100 g)**	**Niacin (B3) (μg/100 g)**	**Total vitamin (mg/100g)**
G. xanthochymus	4.87	0.41	3.75 - 25.10	10.76	37	250	30.62	50	30.97
G. indica	4.83	0.12	5.67	12.06	52	320	33.45	63	34.00
G. mangostana	1.82	0.49	16.1	9.52	50	300	60.43	60	61.05
G. cambogia	3.25 - 4.04	0.34	6.46	8.75	48	275	14.35	45	14.75
G. cochinchinensis	-	-	-	-	-	-	1910.5	-	-
G. pedunculata	4.97	0.20 - 1.25	7.21	8.12	49	276	35.43	47	35.81
G. subelliptica	3.76	0.15	4.38	9.03	50	281	34.45	45	34.94
G. lanceaefolia	3.45	0.13	5.32	8.02	52	283	30.23	45	30.62
G. kydia	4.33	0.42	8.25	10.15	47	267	25.25	50	25.82
G. livingstonei	0.65 - 31.76	1.23 - 19.55	37.67 - 95.02	-	-	-	-	-	-
G. kola	1.74	0.95	5.81 - 21.79	-	-	-	0.69 - 1.25	-	-
G. cowa	3.95	1.35	-	-	-	-	151.40	-	-
G. atroviridis	1.70	0.50	18.20	-	-	-	-	-	-
G. bancana	3.80	0.70	22.70	-	-	-	-	-	-
G. celebica	9.50	0.50	19.70	-	-	-	-	-	-
G. gardneriana	1.35	5.41	10.64	-	-	-	25.23	-	-
G. nervosa	3.90	0.60	14.10	-	-	-	-	-	-
G. nigrolineata	3.20	1.10	20.80	-	-	-	-	-	-
G. parvifolia	0.90	1.10	18.30	-	-	-	-	-	-

Table 2. Mineral composition of Garcinia fruits [14,30,33,36].

***Garcinia* species**	**N (mg/100g)**	**P (mg/100g)**	**K (mg/100g)**	**S (mg/100g)**	**Na (mg/100g)**	**Ca (mg/100g)**	**Mg (mg/100g)**	**Zn (mg/100g)**	**Fe (mg/100g)**	**Mn (mg/100g)**	**Cu (mg/100g)**
G. xanthochymus	-	0.35	28.40	-	2.06	13.07	30.62	-	10.82	-	-
G. indica	-	54.70	750	25.80	581	195	93.00	0.53	147	4.79	0.30
G. mangostana	-	55.20	1050	33.20	41.70	153	62.80	0.86	9.02	2.49	0.28
G. cambogia	-	43.50	500	23.60	39.80	242	72.60	0.82	60.90	3.41	0.23
G. cochinchinensis	-	-	1270.36	-	12.92	240.15	96.59	-	16.29	4.36	7.28
G. pedunculata	-	0.43	63.48	-	2.48	13.21	35.43	0.69	10.12	0.23	0.39
G. subelliptica	-	0.54	43.30	-	1.52	12.33	34.45	-	9.00	-	-
G. atroviridis	-	59.60	531	33.80	3200	150	131	0.24	11.10	4.35	0.25
G. lanceaefolia	-	0.36	52.30	-	1.35	12.54	30.23	-	9.00	-	-
G. kydia	-	0.43	38.70	-	2.54	12.54	25.25	-	10.00	-	-
G. livingstonei	840 - 1294	57.78	1083	2.16	-	760	290	4.06	35.46	24.68	35.46
G. kola	624 -1248	520-720	499-990	-	1.8 -18.00	100-200	166-160	4.00	4.2 - 150	-	1.3 - 2.5
G. morella	-	-	67.68	-	1.00	-	-	0.78	3.10	0.14	0.30

5. Ethnomedicinal properties

Some *Garcinia* fruits are used in folk medicine [37,38]. In some parts of India, sundried slices of *Garcinia* fruits are used to garnish curries and serve local culinary purposes [38]. The fruit rind of *Garcinia cambogia* is used to treat constipation, piles, rheumatism, irregular menstruation, and intestinal parasites [8,39,40]. In Ayurvedic medicine, the fruits of *G. indica* are used to treat wounds, rheumatic pains, bowel complaints, ulcers, inflammation, sores, dermatitis, and dysentery [5,38]. *G. xanthochymus* fruits are used to remove food toxins and treat nausea, diarrhea, and dysentery [41]. In the north-eastern region of India, the dried pulp of *G. morella* is used for stomach ailments, inflammatory disorders, and gastritis [42]. The fruits of *G. mangostana* are used to treat wounds, inflammation, ulcers, and skin infections, while *G. cowa* fruits are used to improve blood circulation and cure dysentery [23,37].

6. Phytochemical constituents of *Garcinia* fruits

Several phytochemical constituents can be found and extracted from the fruits of different *Garcinia sp*. They can be in different parts of the fruit (pericarp, peel, and pulp). The phytochemicals include phenols (83.35-922.5 mg/100 g), anthocyanins (0.022-9.01 mg/kg), and flavonoids (0.30-99.31 mg/100 g) [5,32,35,43]. Different methods have been used to isolate and identify phytochemical constituents. Reported methods include Thin Layer Chromatography (TLC), Infrared Spectroscopy (IR), UV/Vis spectrophotometer, High-Performance Liquid Chromatography (HPLC), Column chromatography (CC), Fourier-Transform Infrared Spectroscopy (FT-IR), High-Performance Centrifugal Partition Chromatography (HPCPC), Liquid Chromatography- tandem Mass Spectrometry (LC-MS/MS), High-Performance Liquid Chromatography Photo-Diode Array (HPLC-PDA), Mass Spectroscopy (MS) and Nuclear Magnetic Resonance (NMR) [6,9,44,45]. Xanthones, benzophenones, organic acids, bioflavonoids, anthocyanins, flavonoids, terpenoids, and fatty acids have been isolated using these methods. The different groups of compounds isolated from *Garcinia* fruits are summarized in Tables 3-10.

Table 3. Xanthones isolated from *Garcinia* fruits.

Garcinia species	Fruit part	Compounds	Reference
G. bracteata	Whole	Garcibracteamones A-J, macluraxanthone, bracteaxanthone XII, 1,3,5,6-tetrahydroxy-4-(1,l-dimethyl prop-2-enyl)-7-(3-methylbut-2-enyl) xanthone, inoxanthone, 10-O-methylmacluraxanthone, 5-O-methylxanthone V_1, assiguxanthone A, 2-deprenyl-rheediaxanthone B, hyperxanthone D, 1,3,7-trihydroxy-2-(2-hydroxy-3-methyl-3-butenyl)-xanthone, 8- methoxy-8,8a-dihydrobractatin, 8-ethoxy-8,8a-dihydrobrac- tatin, bractatin, isobractatin, epiiso-bractatin, doitunggarcinone K, neobractatin, neoisobractatin A, and xerophenone A	[46]
	Whole	Neobractatin	[47]
G. cowa	Pulp	α- Mangostin	[48]
	Whole	Garcicowanone A and B, 9-hydroxycalabaxanthone, β-mangostin, fuscaxanthone A, cowaxanthone D, cowanin, α-mangostin, cowagarcinone E, and rubraxanthone	[49]
	Whole	Garciniacowone A-E, cowaxanthone D, α-mangostin, mangostanin, 6-O-methylmangostanin, 3-O-methylmangostenone D, fuscaxanthonea A and C, rubraxanthone, 3,6-di-O-methyl-γ-mangostin, and β-mangostin	[50]
G. gardneriana	Pulp	Tetrahydroxy-xanthone	[35]
G. humilis	Peel	γ-Mangostin and mangostanol	[18]
G. latissima	Whole	6-Deoxyjacareubin	[51]
G. nujiangensis	Whole	Isojacareubin, nujiangxanthone G, and 1,5,6-trihydroxy-2-prenyl-6′,6′-dimethyl-2H-pyrano(2′,3′:3,4) xanthone	[52]
G. mangostana	Pericarp	Gartanin, γ-mangostin, 1,3,6,7-tetrahydroxy-8-prenyl xanthone, garcinone, 8-deoxygartanin, β-mangostin, α-mangostin, mangosharin, 9-hydroxycalabaxanthone, and 11-hydroxy-1-isomangostin	[53]
	Aril and pericarp	α-Mangostin, asticolorin B, cratoxyarborenone C, 1,3,5-trihydroxy xanthone and gartanin	[54]
	Whole	Garcinone E, γ-mangostin, 8-deoxygartanin, 1,3,7-trihydroxy-2,8-di-(3- methylbut-2-enyl)-xanthone, α-mangostin, and 9-hydroxycalabaxanthone	[55]
	Pericarp	Garcimangosxanthones F and G	[56]
	Pericarp	Garcixanthone A, mangostanaxanthones I and II, garcinone E, β-mangostin, 8-hydroxycudraxanthone G, garcinone C, and cudraxanthone G	[57]
	Pericarp	Smeathxanthone A, α-mangostin, γ-mangostin, mangostenol, 1,3,5-trihydroxy-2-(3-methylbut-2-enyl)-4-(2-hydroxy-3-methylbut-3-enyl) xanthone, and 1,6,7-trihydroxy-8-(3-hydroxy-3-methylbutyl)-6′,6′-dimethylpyrano [2′,3′:3,2] xanthone	[58]
	Hull	Mangostanaxanthones V and V1, β-mangostin, mangostanaxanthone IV, garcinone E, α-mangostin, nor-mangostin, and garcimangosone D	[59]
	Pericarp	Mangostanaxanthones I and II, 9-hydroxycalabaxanthone, parvifolixanthone C, α-mangostin, and rubraxanthone	[60]
	Pericarp	Garcinoxanthones S–V, garcinone E, 11-hydroxy-1-isomangostin, mangostenone E, 1,3,6,7- tetrahydroxyxanthone and α-mangostin	[61]
	Pericarp	Mangoxanthones A and B, allanxanthone A, 5-O-methylxanthone V_1, garcinenone A, and 1,4,6-trihydroxy-5-methoxy-7-(3-methylbut-2-enyl) xanthone	[9]
	Pericarp	1,3,7-Trihydroxy-2-(3-methyl-2-butenyl)-8-(3-hydroxy-3-methyl butyl)-xanthone, 1,3,8-trihydroxy-2-(3-methyl-2-butenyl)-4-(3-hydroxyl-3-methylbutanoyl)-xanthone, garcinone C and D, gartanin, xanthone I, and γ-mangostin	[62]
	Whole	α and γ-mangostin	[63]
	Aril	Mangostanin, 1,7-dihydroxy-3-methoxy-2-(3-methylbut-2-enyl) xanthen-9-one, 1,3,7-trihydroxy-2,8-bis(3-methyl-2-buten-1-yl)-9H-xanthen-9-one, α-mangostin, demethylcalabaxanthone, mangostanol, garcinone D, γ-mangostin, gudraxanthone, 8-deoxygartanin, garcinone E, and β-mangostin	[64]
	Aril	1,7-Dihydroxy-3-methoxy-2-(3-methylbut-2-enyl)-xanthen-9-one, gudraxanthone, 1,3,7-trihydroxy-2, 8-bis-(3-methyl-2-buten-1-yl) − 9 H-xanthen-9-one, γ-mangostin, α-mangostin, β-mangostin, demethylcalabaxanthone, mangostanin, 8-deoxygartanin, garcinone E, garcinone D, and mangostanol	[20]
	Pericarp	Garcimangosxanthone F and G	[56]

Garcinia species	Fruit part	Compounds	Reference
	Pericarp	8-Desoxygartanin, gartanin, α-mangostin, β-mangostin, garcinone D, γ-mangostin, and 9- hydroxycalabaxanthone	[45]
	Pericarp	Mangostanin, 8-deoxygartanin, gartanin, garcinone B and E, trapezifolixanthone, padiaxanthone, tovophyllin A, 1,5,8-trihydroxy-3-methoxy-2 [3-methyl-2-butenyl]xanthone, 1,3,7-trihydroxy-2,8-di-(3-methylbut2-enyl) xanthone, mangostenone D, 2-geranyl-1,3,5-trihydroxy xanthone (mangostinone), 1,7-dihydroxy-2-(3-methylbut-2-enyl)-3-methoxy xanthone, and 7-O-demethyl mangostanin	[65]
	Pericarp	Garcinone E, α-mangostin, nor-mangostin, gartanin, and mangostanaxanthone VI	[66]
	Pericarp	α-Mangostin, 1,3,6-trihydroxy-2-(2,3-dihydroxy-3-methyl butyl)-7-methoxy-8-(3-methyl-2-butenyl) xanthone, 1,3,6-trihydroxy-2-(3-methyl-2-butenyl)-7-methoxy-8-(2,3-dihydroxy-3-methyl butyl) xanthone, 1,3,6-trihydroxy-2-isopentyl-7-methoxy-8-(2,3-dihydroxy-3-methyl butyl)-9H-xan then-9-one, tetrahydro-α-mangostin, 1,3,6-trihydroxy-7-methoxy-8-(2,3-dihydroxy-3-methyl butyl)-2H-furo[3,2-b]xant hen-5(3H)-one, 1,3,6-trihydroxy-7-methoxy-8-isopentyl-2H-furo[3,2-b] xanthone-5(3H)-one, 2-(2,3-dimethoxy-3-methyl butyl)-8-isopentyl-1,3,6,7-tetra methoxy-9H-xanthen-9- one, 4-chloro-α-mangostin, 4-bromo-α-mangostin, 4,5-dibromo-α-mangostin, 4-bromo-tetrahydro-α-mangostin, and 4,5-dibromo-tetrahydro-α-mangostin	[67]
G. oblongifolia	Whole	1,3,6,7- Tetrahydroxyxanthone, nigrolineaxanthone T, oblongixanthone A and C, dulxanthone A, xanthone V1a, garcinone (B and E), and dulxanthone B	[68]
	Whole	1,4,6,7-Tetrahydroxyxanthone, 1,7-dihydroxy xanthone, and 3-methoxy-1,6,7-trihydroxy xanthone	[6]
G. pedunculata	Pericarp	Pedunxanthones D-F, 6-O-demethyloliverixanthone, fuscaxanthone A, cowanin, norcowanin, α-mangostin, mangostanol, 3-isomangostin, and 1,7-dihydroxy xanthone	[69]
	Pulp and rind	9-Hydroxycalabaxanthone and garcinone A	[70]
	Pericarp	Garcinone E, α, β and γ-mangostins	[71]
G. travancorica	Whole	α-Mangostin, γ-mangostin, 1,5-dihydroxy-3-methoxy xanthone, 4-(1,1-dimethyl prop-2-enyl)-1,3,5,8-tetrahydroxy-xanthone, garcinia xanthone E, garcinone A, garcinone B, garcinone C, and polyanxanthone C	[72]
G. xanthochymus	Pulp	1,4,5-Trihydroxyxanthone, 1,3,7-trihydroxy xanthone, 1,3,5-trihydroxy xanthone, 1,5,6-trihydroxy-3-methoxy xanthone, 1,3,6-trihydroxy-7-methoxy xanthone, 2,5-dihydroxy-1-methoxyl xanthone, and 1,3,5,6-tetrahydroxy-2-isoprenyl xanthone	[1]

Table 4. Reported benzophenones from *Garcinia* fruits.

Garcinia species	Fruit part	Compounds	Reference
G. brasiliensis	Epicarp	7-Epiclusianone	[73]
	Epicarp	7-Epiclusianone	[74]
	Epicarp	7-Epiclusianone	[75]
G. bracteata	Whole	Garcibracteamones H-J	[46]
G. cambogia	Pulp	Guttiferone J	[76]
	Whole	Garcinol and guttiferones K and M	[77]
	Whole	4,8-Epi-uralione F, 4,8-epi-uralione G, uralione S, coccinone J, 6-epi-coccinone C, coccinone I, 36-hydroxy-guttiferone J, multiflorone I, garciniagifolone F, 36-hydroxy-garciniagifolone F, garcinol, guttiferone K, guttiferone I, 14-deoxyisogarcinol, (1S,5R,7R,30S)-14-deoxyisogarcinol, coccinone, isogarcinol, and guttiferone J	[76,78]
G. cowa	Pulp	Xanthochymol	[48]
G. dulcis	Rind and peel	Garcinol	[79]
	Pulp	Garcinol	[80]
G. gardneriana	Pulp	7-Epiclusianone	[35]
G. livingstonei	Pulp	Guttiferone A	[81]
G. mangostana	Pericarp	Garcimangophenones A and B	[66]
	Pericarp	Garcimangosone D, 2,4,6,3`,4`,6`-hexahydroxybenzophenone and 6-O-β-D-glucopyranosyl- 2,4,6,3`,4`,6`-hexahydroxybenzophenone	[4]

Garcinia species	Fruit part	Compounds	Reference
	Hull	2,4,6,3`,5`-Pentahydroxybenzophenone	[59]
G. morella	Pericarp	Garcinol	[42]
G. nujiangensis	Whole	Nujiangefolins A, B, and C, symphonone H, garcimultiflorone E6, and (-)-cycloxanthochymol	[52]
G. multiflora	Whole	Isohypersampsonone F, isohookerione J, isosampsonione H, epi-garcimultiflorone P, and garcimultinone C	[82]
G. madruno	Epicarp	Garcinol	[83]
G. oblongifolia	Whole	Garcicowin (B, C and D), 30-epicambogin, oblongifolin (A, C and L), and garciyunnanin B	[68]
	Whole	Isogarcinol, 13,14- didehydoxyisogarcinol, garcinol, acylphloroglucinol, garcimultiflorone K, sampsonione P, garcoblones A−F, and 7-epiclusianone	[6]
G. pedunculata	Pulp and rind	Garcinol	[70]
G. schomburgkian	Whole	Schomburgkianones A-H, guttiferone K, oblongifolin C, and garciyunnanin A	[84]
G. travancorica	Whole	Gambogenone, aristophenone A, garcinol, and garciyunnanin A	[72]
G. xanthochymus	Whole	Garcinoxanthocins (A and B), garcinophenylpropanoic acid, spiritone, 14-deoxygarcinol, xanthochymol, garcicowin, isogarcinol, cycloxanthochymol, and garcinialiptone	[85]
	Whole	Aristophenone A, cycloxanthochymol, gambogenone A, guttiferone E, guttiferone H, isoxanthochymol, and xanthochymol	[81]
	Pulp	2,4,6,3′,4′-pentahydroxybenzophenone-2-O-βD-glucopyranoside, and 2,4,6,3′,4′-pentahydroxybenzophenone	[86]
	Pulp	Garcixanthochymones A–E	[1]
	Whole	Xanthochymol, guttiferone E, cycloxanthochymol, isoxanthochymol, 14-deoxygarcinol, 14-deoxy-isogarcinol, 7-epi-isogarcinol, coccinone C, garcim-1, nujiangefolins A and B, and garcim-2	[87]
	Whole	Oblongifolin F, isoxanthochymol, and aristophenone A	[44]
	Seed and pulp	Garxanthochins A- C and garcinialiptones L, F and T	[88]
	Whole	7-Epi-isoxanthochymol, 7-epi- cycloxanthochymol, garcimultiforone E, nujianggefolin C, coccinone D and E, nujiangefolin B, and garcimultiforone I	[89]
	Whole	Xanthochymol and garcinol	[90]
G. *yunnanensis*	Whole	Garciyunnanins C-L	[91]

Table 5. Bioflavonoids isolated from *Garcinia* fruits.

Garcinia species	Fruit part	Compounds	Reference
G. bransiliensis	Epicarp	Fukugetin	[75]
G. cambogia	Rind	Amentoflavone	[16]
G. dulcis	Rind	Morelloflavone	[79]
G. gardneriana	Pulp	GB-2a, fukugetin, volkensiflavone, GB-2a1-7-O-glucoside, fukugiside, amentoflavone, and 7-O-methylamentoflavone	[35]
G. madruno	Epicarp	Morelloflavone, GB-1a, GB-2a, volkensiflavone, mentoflavone, and fukugiside	[92]
	Epicarp	Amentoflavone, GB-2a, and morelloflavone	[83]
G. oblongofolia	Pulp	GB-1a 7′′-O-β-D-glucoside, volkensiflavone, morelloflavone, GB-2, spicataside, GB-2a, GB-1a, and amentoflavone	[68]
G. pedunculata	Pulp and rind	GB-1a	[70]
G. schomburgkiana	Whole	GB-1a, GB-2a, morelloflavone, and volkensiflavone	[84]
G. travancorica	Whole	Morelloflavone, GB-1a, GB-2, GB-2a, and fukugiside	[72]
G. xanthochymus	Whole	Volkensiflavone, fukugetin, fukugeside, GB 1a, GB 1a glucoside, GB 2a, GB 2a glucoside, and amentoflavone	[44]
	Pulp	Amentoflavone, fukugetin, fukugiside, and volkensiflavone	[81]
	Pulp	Volkensiflavone, GB-2a and (±) fukugetin	[1]

Table 6. Anthocyanins present in *Garcinia* fruits.

Garcinia species	Fruit part	Compounds	Reference
G. cambogia	Rind	Cyanidin-3-O-sambubioside and cyanidin-3-O-glucoside	[93]
G. indica	Rind	Cyanidin-3-sambubioside, peonidin-3- arabinoside, pelargonidin-3-glucoside, peonidin-3,5-O-diglucoside, peonidin 3-glucoside, peonidin-3-galactoside, delphinidin-3-arabinoside, dephinidin 3-glucoside, pelargonidin 3-diglucoside-5-glucoside, and methyl delphinidin glycoside	[5]
G. mangostana	Pericarp	Cyanidin-O-sophoroside and delphinidin-O-pentoside	[94]
	Pericarp, aril, and pulp	Cyanidin-3-glucoside	[43]

Table 7. Flavonoids isolated from *Garcinia* fruits.

Plant species	Fruit part	Compounds	Reference
G. brasiliensis	Pulp, seed, and peel	Catechin and hesperitin	[95,96]
G. cambogia	Rind	Quercetin, vitexin, rutin, naringin, and catechin	[16]
G. humilis	Seed	Catechin, hesperitin, procyanidin A2, Bi, B2 and C1, and rutin	[97]
	Rind and pulp	Procyanidin B2	[12]
	Peel	Epicatechin and apigenin 6-C-glucoside	[18]
G. gardneriana	Pulp	Epicatechin, vitexin, vitexin-O-rhamnoside, and isovitexin	[35]
G. indica	Rind	Naringenin, apigenin, quercetin, catechin, luteolin, hesperetin, and myricetin	[5]
G. mangostana	Hull	Aromadendrin-8-C-glucopyranoside and epicatechin	[98]
	Whole	Epicatechin, catechin, and rutin	[63]
	Hull	Epicatechin	[59]
	Pericarp	(+)-Epicatechin, taxifolin-O-rhamnoside, and quercetin-3-O-rutinoside	[94]
	Pericarp	Epicatechin	[4]
	Pericarp	(-)-Epicatechin	[57]
G. xanthocymus	Pulp	6-prenyl-4’, 5,7-trihydroxflavone and naringenin	[1]
	Whole	Catechin and epicatechin	[99]
	Whole	Epicatechin	[100]

Table 8. Terpenoids reported from different parts of *Garcinia* fruits.

Plant species	Fruit part	Compounds	Reference
G. atroviridis	Whole	Cassaidine	[101]
G. kola	Pulp	Lupeol	[102]
G. mangostana	Pulp	Thymol-β-D-glucopyranoside, catalposide, gibberellin A, ginkgolide C, montanol, and salvinorin A	[54]
G. speciosa	Whole	Garciosaterpenes D, E and F, wallichinanes A and E	[103]

Table 9. Organic acids present in *Garcinia* fruits.

Plant species	Fruit part	Organic acid	Reference
G. atroviridis	Whole	Citric acid, oxalosuccinic acid, homoisocitrate, and hydroxycitric acid	[101]
G. cambogia	Rind	Citric acid and (-)-hydroxy citric acid	[104]
	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]
	Rind	(−) Hydroxycitric acid and (−) hydroxycitric acid lactone	[105]

Plant species	Fruit part	Organic acid	Reference
G. dulcis	Rind and pulp	Citric acid	[79]
G. gardneriana	Pulp	Hydroxycitric acid lactone	[35]
G. humilis	Rind and pulp	Hydroxycitric and citric acid	[12]
G. indica	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]
	Rind	Hydroxycitric acid	[5]
G. kydia	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]
G. lanceaefolia	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]
G. madruno	Epicarp	Hydroxycitric acid, citric acid, and hydroxycitric acid lactone	[92]
G. mangostana	Aril and pericarp	Galacturonic acid, L- (+)-tartaric acid, aspartic acid, maleic acid, and ribonic acid	[54]
	Pericarp	Oxalic, quinic, malic, ascorbic, shikimi, citric and fumaric acids	[94]
	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]
G. pedunculata	Perocarp	Hydroxycitric acid lactone	[71]
	Pulp and rind	Hydroxycitric acid lactone and hydroxycitric acid	[70]
	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, and oxalic acid	[14]
G. subelliptica	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]
G. travancorica	Whole	Hydroxycitric acid and hydroxycitric lactone acid	[72]
G. xanthochymus	Whole	Oxalic, galacturonic, tannic, ascorbic, malic, succinic, and citric acid	[100]
	Rind	Malic acid, (-) hydroxycitric acid (HCA), citric acid, tartaric acid, oxalic acid, and acetic acid	[14]

Table 10. Fatty acids present in *Garcinia* fruits.

Plant species	Fruit part	Fatty acid	Reference
G. cambogia	Seeds	Myristic, linoleic, oleic, margaric, and arachidic acid	[106]
	Seeds	Palmitic, stearic, oleic, linoleic, arachidic, and gondoic acid	[107]
	Pericarp and seeds	Capric, undecanoic, lauric, palmitic, stearic, oleic, and linolelaidic acid	[108]
G. dhanikhariensis	Seeds	Stearic, oleic, palmitic, arachidic, palmitoleic, 11-eicosenoic, and linoleic acid	[109]
G. dulcis	Pulp	Octadecanoic acid and n-hexadecanoic acid	[110]
G. gaudichaudii	Seeds	Oleic acid, stearic acid, and linoleic acid	[111]
G. livingstonei	Seeds	Myristic, palmitic, palmitoleic, steraic, oleic, linoleic, linolenic, arachidic, behenic, and heptadecanoic acid	[30]
G. hanburyi	Seeds	Oleic acid, stearic acid, and linoleic acid	[111]
G. indica	Pericarp and seeds	Capric, undecanoic, lauric, palmitic, stearic, oleic, and linolelaidic acid	[108]
G. kola	Pulp	Octadecanoic, eicosanoic, pentadecanoic, and tetradecanoic acid	[102]
G. mangostana	Pericarp	Palmitic, stearic, oleic, and linoleic acid	[94]
G. multiflora	Seeds	Oleic acid, stearic acid, and linoleic acid	[111]
G. xanthochymus	Pericarp and seeds	Capric, undecanoic, lauric, palmitic, stearic, oleic, and linolelaidic acid	[108]
	Whole	Capric, lauric, palmitic, stearic, oleic, linoleic, and α-linoleic acid	[100]
	Seeds	Myristic, palmitic, stearic, palmitoleic, oleic, linoleic, linolenic, arachidic, and behenic acid	[112]

6.1. Xanthones and benzophenones.

The major phytochemical constituents in *Garcinia sp*. are xanthones (Figure 1), followed by benzophenones. Xanthones, oxygen- containing heterocyclic compounds, are a group of secondary metabolites belonging to the polyphenolic group [8,113]. They are classified into six groups depending on the nature of the substituents in the dibenzo-γ-pirone scaffold: simple oxygenated xanthones, xanthone glycosides, prenylated xanthones, bisxanthones, xanthonolignoids, and miscellaneous xanthones [8,114]. The highest number of xanthones has been reported in *G. mangostana*, followed by *G. cowa* [8]. Xanthones are responsible for the species' antidiabetic, anticancer, antibacterial, hepaprotective, and antioxidant activities [47,55,64,115].

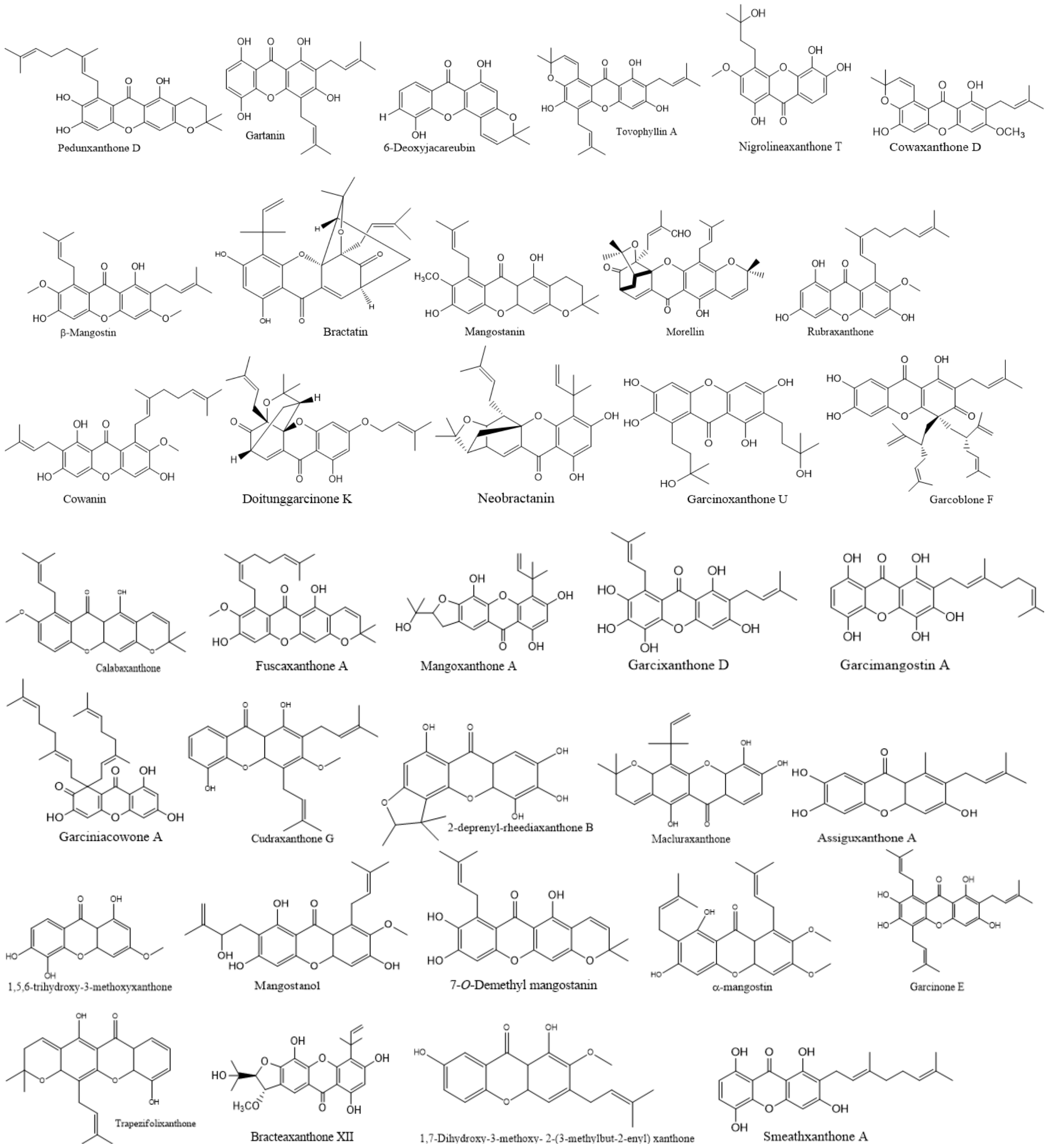

Figure 1. Structures of xanthones present in *Garcinia* fruits.

Benzophenones (Figures 2 and 3) are a class of compounds sharing a common phenol-carbonyl-phenol skeleton synthesized through the mixed shikimic acid and acetate pathway [8,116]. More than 300 members of natural benzophenones consist of oxidized and polyisoprenylated structures [116]. Benzophenones (77 %) have been reported from the Clusiaceae family, most of which were isolated from the genus *Garcinia* [10,116]. Different biological activities (antitumor, anti-inflammation, antioxidant, anti-obesity, and antidiabetic) are attributed to the presence of benzophenones [5,6,9,80]. The fruits are also rich sources of flavonoids, anthocyanins, terpenoids, and organic acids, as depicted in Figures 4 and 5, and they have many biological activities.

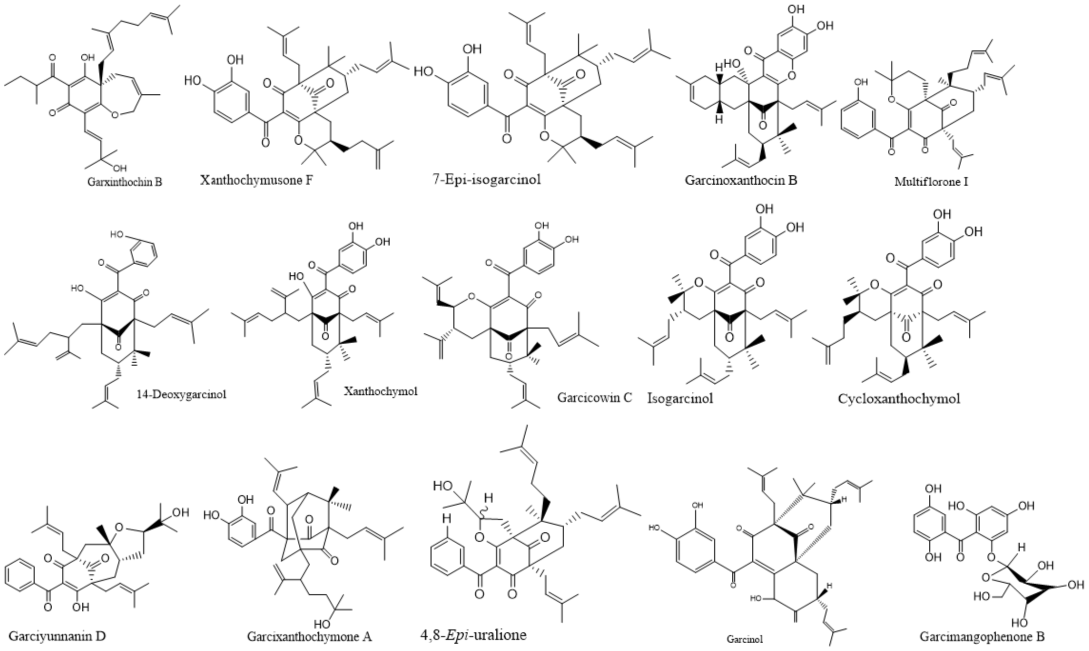

Figure 2. Benzophenones present in *Garcinia* fruits.

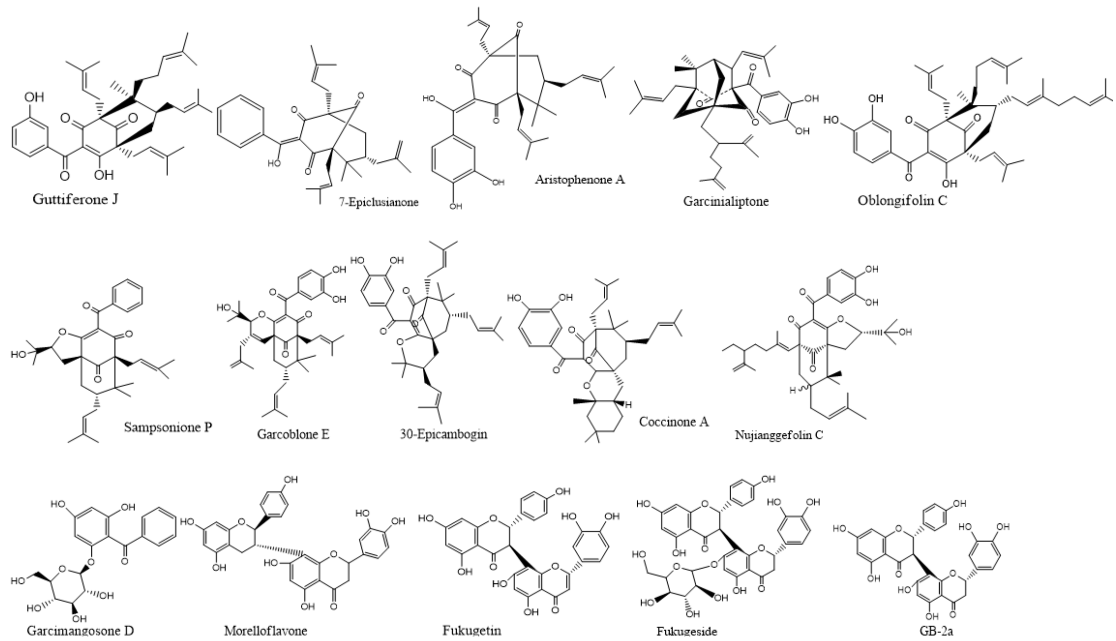

Figure 3. Structures of benzophenones and bioflavonoids reported from *Garcinia* fruits.

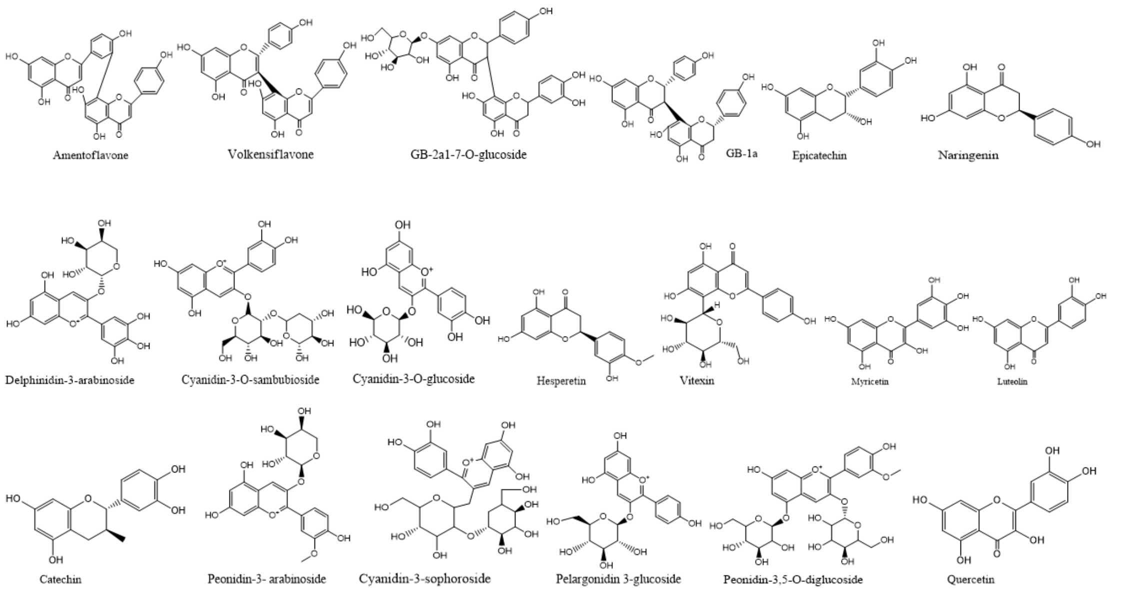

Figure 4. Structures of bioflavonoids, flavonoids, and anthocyanins present in *Garcinia* fruits.

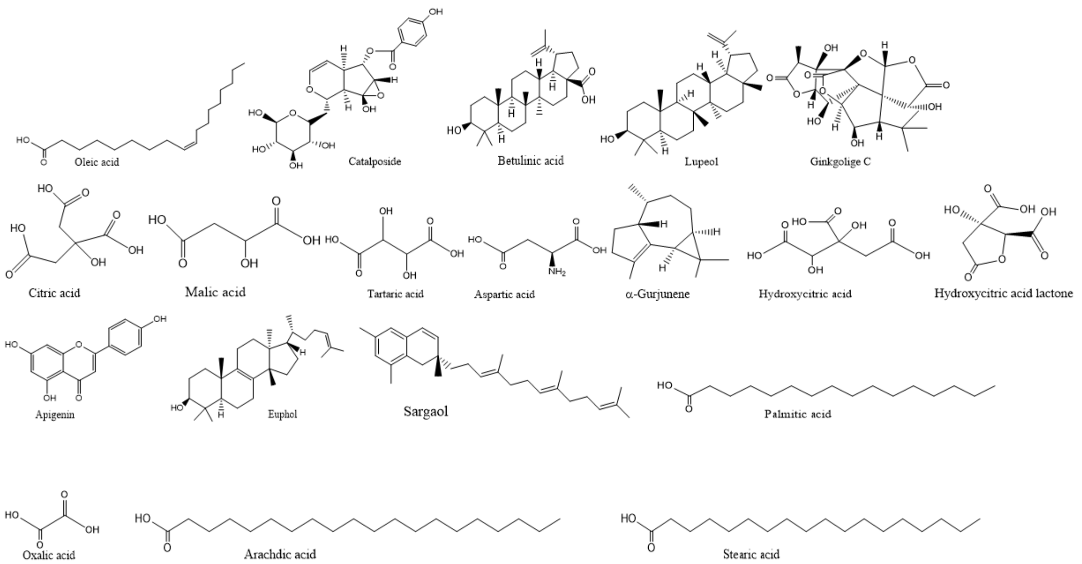

Figure 5. Structures of terpenoids, organic acids, and fatty acids reported from *Garcinia* fruits.

7. Biological Activities of *Garcinia sp.*

Researchers have found beneficial bioactive compounds in different *Garcinia* fruits. The bioactive compounds contribute to their biological activities [117]. The bioactive compounds of the fruit extracts from different *Garcinia sp*. have been reported to exhibit a variety of biological activities in both *in vitro* and *in vivo* models, such as anti-inflammatory, antitumor, antioxidant, antimicrobial, anti-COVID 19, anti-obesity, anti-ulcer and antidiabetic [5,16,46,48,76,78,101,118,119].

7.1. Anti-obesity activity.

Obesity is an undesirable condition that is associated with health disorders. Apart from exercise, natural supplements are preferred due to their low-risk effects [104,120]. Some *Garcinia* fruits are used to manage weight [40,104]. *Garcinia* acid (hydroxycitric acid), garcinol, and cyanidin -3-glucoside are responsible for the anti-obesity effects of the fruits [5,79,121]. In a recent study, the anti-obesity activity of *G. cambogia* ethanoic fruit extract in high-fat diet-induced obese mice using bioactivity-based molecular networking and Oil Red O staining on 3T3-L1 and C3H10T1/2 adipocytes was observed [76]. The isolated polycyclic polyprenylated acylphloroglucinols (guttiferone J, garcinol, and 14-deoxygarcinol) yielded a lipid-lowering effect in adipocytes [76].

Abdominal obesity, hypertension, increased left ventricular diastolic stiffness, decreased glucose tolerance, fatty liver, and reduced *Bacteroidia* with increased *Clostridia* in the colonic microbiota were observed in male Wistar rats fed with high-carbohydrate, high-fat diet for 16 weeks [79]. *G. dulcis* fruit rind supplementation improved cardiovascular and liver structure and function and attenuated changes in the colonic microbiota [79]. When garcinol isolated from *G. indica* rind extract was administered to high-fat diet-fed mice, it displayed low visceral fat accumulation [121]. Furthermore, the *in vitro* study revealed that the extract inhibited adipogenesis, increased uncoupling protein-1 (UCP1), and reduced the endoplasmic reticulum stress in the adipose tissues [121].

7.2. Antifungal activity.

Retardation in the activity of drugs against fungi infections and the development of resistance by microbes has necessitated the search for natural products as alternatives [8,119,122]. Several researchers have demonstrated the antifungal potential of different species of *Garcinia* fruits. Akintelu, Olugbeko, and Folorunso [119] conducted a study on the antifungal activity of synthesized silver nanoparticles (AgNPs) extracted from *G. kola* pulp. The synthesized AgNPs showed potent activity against tested fungi strains with inhibition zones ranging from 6 to 17 mm, comparable to the control (18 to 24 mm) [119].

Suwanmanee, Kitisin, and Luplertlop [123] tested the antifungal activity of *G. atroviridis* fruit extract against several strains of fungi (*A. niger, M. gypseum, C. albicans, M. canis, S. cerevisiae, E. floccosum, T. mentagrophytes, T. tonsurans, and Penicillium sp.*) and revealed that the phenols found in the species have antifungal activity. However, the study did not specify the actual bioactive compounds responsible for this activity. A group of researchers looked at the benzophenones isolated from *G. xanthochymus* fruits. It was reported that xanthochymol and garcinol showed multiple activities against *C. albicans* biofilms, and it was concluded that these bioactive compounds can be used in antifungal treatments [90].

7.3. Antidiabetic activities.

Diabetes mellitus is a metabolic disorder associated with hyperglycemia and is characterized by dysfunction of cells in the pancreatic islets of Langerhans [122,124]. Due to the adverse effects and unaffordability of the drugs used to treat diabetes, researchers are looking for plant alternatives with nutraceutical potential [124]. The *in vitro* antidiabetic activity of α-mangostin and β-mangostin isolated from *G. cowa* young fruits displayed potent α-glucosidase inhibitory with half maximal inhibitory concentration (IC_{50}) values of 7.8 ± 0.5 and 8.7 ± 0.3 μM, respectively [50]. Garcimangostin A had the most potent α-amylase inhibitory effect of 94.1% compared to acarbose (96.7%) and concluded that mangosteen can decrease postprandial glucose absorption [125]. The activity of the xanthone is attributed to the moiety insertion in the active site of the enzyme via the H-bonds network and π–π interactions [125].

Oral administration of the aqueous extract of *G. mangostana* rind (100 and 200 mg/kg body weight) in a high-fat diet (5 g/day up to five weeks) and streptozotocin-induced T2D nephropathy of albino mice significantly improved glucose level and lipid metabolism, enhanced mitochondrial integrity and insulin sensitivity, diminished oxidative stress, and inhibited lipid peroxidation process and inflammation [126]. The results revealed that mangosteen vinegar rind induced α-amylase inhibitory activities with the IC_{50} value of 422.82 ± 7.83 µg/mL [126]. Their subsequent study on the pericarps of *G. mangostana* on high-fat diet and streptozotocin-induced mice disclosed that α-mangostin and γ-mangostin inhibited pancreatic-α-amylase with the IC_{50} value of 409.59 ± 6.81 µg/mL [127].

The *in vitro* study on the α-amylase inhibition of xanthones isolated from the pericarps of *G. mangostana* revealed that garcixanthone D (1,3,5,6,7-pentahydroxy-2,8-bis(3-methylbut-2-enyl)-xanthone), garcimangostin A, and garcinone E had the most potent inhibition activity and can therefore help to decrease postprandial glucose absorption [57,128]. A more recent study on the same species focussed on the α-amylase inhibitory potential of benzophenones. Their findings disclosed that garcimango phenones A and B had significant activity (IC_{50} 9.3 and 12.2 µM, respectively) compared to acarbose (IC_{50} 6.4 µM) [66]. Mangoxanthone A has also been reported to show moderate inhibitory activities against α-glucosidase and α-amylase [9].

7.4. Antibacterial activities.

Several compounds isolated from different *Garcinia* fruits have been shown to possess antibacterial activity. The acetone extracts of the bioactive compounds from *G. cowa* immature fruits were isolated and examined for their antibacterial activity against Gram-positive bacteria (*B. cereus* TISTR 688, B. subtilis TISTR 008, *M. luteus* TISTR 884, and *S. aureus* TISTR 1466) and Gram-negative bacteria (*E. coli* TISTR 780, *P. aeruginosa* TISTR 781, *S. typhimurium* TISTR 292, and *S. epidermidis* ATCC 12228) [49]. The researchers reported that garcicowanones A and B, 9-hydroxycalabaxanthone, β-mangostin, fuscaxanthone A, cowaxanthone D, cowanin, α-mangostin, cowagarcinone E, and rubraxanthone showed antibacterial activities against the Gram-positive strains (*B. cereus*, *B. subtilis and M. luteus*) and the Gram-negative strain, *S. epidermidis* [49].

A study carried out by Zheng et al. [91] prepared ethanolic extracts to evaluate the antimicrobial activity of *G. yunnanensis* fruits and reported that garciyunnanins C and D were potent α-hemolysin inhibitors against Methicillin-resistant *S. aureus* (MRSA). At *in vitro* level, the xanthones (garcinianones A and B and rubraxanthone) isolated from the young fruits of *G. cowa* showed antibacterial activity against *B. subtilis* TISTR 088 with identical minimum inhibitory concentration (MIC) values of 2 µg/mL while garciniacowone A, mangostanin, and rubraxanthone exhibited antibacterial activity against *B. cereus* TISTR 688 with identical MIC values of 4 µg/mL [50]. A recent study conducted by Khan, Jaafar, and Rukuyadi [129] evaluated the antimicrobial potential of *G. atroviridis* fruit extracts. The ethanolic fruit extracts showed potent antimicrobial activity against *S. aureus* ATCC 25923, *L. monocytogenes* ATCC1 9112, *S. enterica* ser.

Typhimurium ATCC 14028, and *E. coli* ATCC 43895, and the researchers concluded that the extracts can be used as a natural preservative for reducing the microbial population [129].

7.5. Anti-inflammatory and anti-allergic activities.

Inflammation is part of the body's defense mechanism, and it involves the biosynthesis of prostaglandins that are responsible for pain sensation [8,122]. Most studies indicate that the bioactive compounds extracted from different *Garcinia sp*. reduce allergic inflammatory responses. In lipopolysaccharide (LPS)-activated human leukemia monocytic cell line (THP-1) and murine macrophage cell line (Raw 264.7) macrophages, garcinol isolated from *G. dulcis* fruits inhibited the production of pro-inflammatory cytokines and mediators and decreased the secretion of tumor necrosis factor-alpha (TNF-α), interleukin 6 (IL-6), interleukin-1β (IL-1β), prostaglandin E2 (PGE2), and nitrogen oxide (NO) [80]. Similarly, Xue et al. [46] reported that neobractatin and bractatin isolated from *G. bracteata* showed significant inhibitory effects against nitric oxide production assay in lipopolysaccharides-stimulated RAW 264.7 cells.

In another study by Mohan et al. [130], α-mangostin isolated from *G. mangostana* inhibited the production of PGE2 and nitric oxide, and nitric oxide synthase (iNOS) protein expression and the translocation of nuclear factor kappa B (NFκB) with cyclooxygenase-2 (COX-2) enzyme suppression. At the *in vivo* level, the xanthone inhibited the total leukocyte migration [130]. The inhibitory effect of garcinol isolated from *G. indica* fruit rind against 12-0-tetradecanoylphorbol 13-acetate (TPA)-induced skin inflammation in mice was studied and the researchers reported that it reduced TPA-induced activation of extracellular signal-regulated kinases (ERK), c-Jun-N-terminal kinases (JNK), p38 mitogen-activated protein kinase (MAPK), and phosphatidylinositol 3-kinase (PI3K)/Ak [131]. Likewise, 4,8-epi-uralione F from *G. cambogia* fruits inhibited the production of in lipopolysaccharide (LPS)-stimulated RAW264.7 with an IC_{50} value of 41.60 ± 0.17 μM and concealed inducible NO synthase (iNOS) expression [78]. They, therefore, concluded that the isolated polyisoprenylated benzophenones from *G. cambogia* can be used as inflammatory inhibitors.

7.6. Cytotoxic activities.

Cytotoxic activity is pivotal in contravening the growth of cancer cells, and natural compounds are explored as nutraceuticals [27,122]. A healthy and nutritious diet lowers the chance of developing cancer and helps alleviate the side effects of cancer treatments [122,132]. The *in vitro* antiproliferative activities of the ethanoic extract of *G. xanthochymus* fruits evaluated against human tumor cells (HepG2, A549, SGC7901, and MCF-7) revealed that the isolated five polycyclic polyprenylated acylphloroglucinols (Garcixanthochymone A-E) inhibited cancer proliferation from different tissues and concluded that the fruits could further be developed as potent candidates for treating and preventing cancer, and its related disorders [1]. Garcinoxanthocins A and B, 14-deoxygarcinol, xanthochymol, garcicowin C, isogarcinol, and cycloxanthochymol isolated from the fruits of the same species inhibited the viability of glioma cancer cells with IC_{50} values in the range of 1.6-6.5 µM [85]. Xu et al. [87] revealed that 7-epi-isogarcinol and xanthochymusone F induced apoptosis and inhibited cell migration in Huh-7 cells by downregulating the signal transducer and activator of the transcription 3 (STAT3) signaling pathway. A recent study on the species has revealed that garxanthochin B isolated from the seeds had moderate inhibitory activities (IC_{50} values of 14.71- 24.43 µM) against five human cancer cell types (HL-60, A549, SMMC-7721, MDA-MB-231, and SW480) [88].

The *in vitro* cytotoxic analysis of dichloromethane pulp extract of *G. oblongifolia* found that garcoblone F had significant activities on nasopharyngeal carcinoma (NPC) cell lines (CNE1 and CNE2) with the IC_{50} values of 7.8 ± 0.2 and 9.1 ± 0.3 µM, respectively [6]. Garcoblone F can elevate reactive oxygen species (ROS) levels in the cell lines that induce mitophagy to promote Caspase-9/GSDME-mediated pyroptosis [6]. A study that examined 7-O-demethyl mangostanin isolated from *G. mangostana* pericarps against seven cancer cell lines (CNE-1, CNE-2, A549, H490, PC-3, SGC-7901, and U87) divulged that the xanthone had potential cytotoxic activity for cancer cells [65]. Similarly, neobractatin and doitunggarcinone K isolated from *G. bracteata* showed potent activities against three human cancer cell lines (HepG2, T98, and MCF-7) with IC_{50} values ranging from 3.21 to 6.27 µM [46]. Recent findings have shown that neobractatin increased the expression of Elav-like family member 6 (CELF6) at both the mRNA and protein levels [47].

7.7. Antioxidant activities.

Antioxidants are natural compounds that are used to inhibit oxidation and reduce the concentration of transition metal ions or free radical damage by neutralizing and scavenging them [23,133]. Xanthones, phenolic acids, anthocyanins, benzophenones, and flavonoids are responsible for the antioxidant activity of *Garcinia sp*. [5,61,64]. Naturally, biological systems have antioxidant defense mechanisms. However, these mechanisms cannot be sufficient, and researchers have embarked on finding naturally occurring antioxidant compounds in fruits.

A recent study has shown that a xanthone, mangostanin, can protect and restore hydrogen peroxide-induced oxidative damage by reducing the generation of intracellular reactive oxygen species and preventing the activation of protein kinase B, extracellular signal-regulated kinase and other cellular pathways [64]. Kureshi et al. [134] determined the antioxidant capabilities of the aqueous extracts from *G. indica* and *G. cambogia* synthesized with gold nanoparticles (AuNPs) using 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) assay. The synthesized AuNPs demonstrated significant scavenging properties, 51.05% (*G. indica*) and 44.05% (*G. cambogia*), comparable to the ascorbic acid standard (94.11%) at 100 µg/mL. The aqueous extracts of *G. indica* and *G. cambogia* showed 45.90% and 36.49% inhibition at the same concentration. The study suggested that the free radical scavenging activities of the AuNPs can be attributed to the secondary metabolites (phenolic constituents present in the extract) involved in the synthesis [134]. The *in vitro* antioxidant activity in the DPPH of the methanolic extract of *G. mangostana* revealed that garcinone E, 1,3,6,7-tetrahydroxyxanthone and garcinoxanthone U displayed significant DPPH scavenging capacity with IC_{50} values of 68.55, 63.05, and 28.45 µM, respectively, comparable to ascorbic acid (IC_{50} = 48.03 µM) [61].

Table 11. Phytoconstituents isolated from *Garcinia* fruits and their biological activities.

Plant species	Plant part	Compounds	Activity	Experimental model	Reference
G. atroviridis	Whole	Emmotin A, colupone, persicaxanthin, citric acid, monoglyceride citrate, and 2,4-dinitro-1-(3-nitrophenoxy) benzene	Antidiabetic	α-glucosidase and α-mylase assays	[101]
	Whole	Gallic acid	Antioxidant	DPPH, ABTS, and FRAP assays	[43]
	Whole	Hydroxycitric acid and palmitic amide	Anticancer	Sulphorhodamine B (SRB) assay on L6 myoblast cells	[101]
G. cowa	Pulp	Xanthochymol and α- mangostin	Anti-ulcer	Ethanol induced gastric mucosal lesions in Wistar rats	[48]
	Whole	α-mangostin and β-mangostin	Antidiabetic	α-glucosidase assay	[50]
	Whole	α-mangostin	Antibacterial	Dilution method	[49]
	Whole	Garcinianone A, garcinianone B, mangostanin, and rubraxanthone	Antibacterial	Agar micro-dilution against *B. subtilis*	[50]
G. cambogia	Rind	Garcinol	Anti-obesity	High-fat diet-induced obesity in mice	[121]
	Rind	Naringin, catechin, and gallic acid	Anti-COVID 19	Human Coronavirus (COVID-19) Antiviral Assay	[16]
	Whole	4,8-epi-uralione F	Anti-inflammatory	Nitric Oxide (NO) production assay in lipopolysaccharide (LPS)-stimulated RAW264.7 macrophages.	[78]
	Whole	Guttiferone J, garcinol, and 14-deoxygarcinol	Anti-obesity	Polyethylene glycol-induced obese mice	[76]
G. bracteata	Whole	Neobractatin and doitunggarcinone K	Antitumor	HepG2, T98, MCF-7 cell lines	[46]
	Whole	Neobractatin and bractatin	Anti-inflammatory	Nitric Oxide (NO) production assay in lipopolysaccharides-stimulated RAW 264.7 cells	[46]
	Whole	Neobractatin	Antitumor	HeLa and K562 cells *in vitro* and *in vivo*	[47]
G. brasiliensis	Seed	Hesperitin, vanillic acid, and formononetin	Antioxidant	DPPH, ABTS, and FRAP assays	[136]
	Epicarp	7-Epiclusianone	Anti-cancer	MTS assay	[73]
	Epicarp	7-Epiclusianone	Schistosomicidal	Swiss mouse models infected with cercariae	[75]
	Epicarp	7-Epiclusianone	Photoprotective	UVB damage-induced decrease in endogenous reduced glutathione and cell viability of L929 fibroblasts	[74]
G. dulcis	Whole	Morelloflavone	Diuretic	Two-kidneys-one-clip (2K1C) renovascular hypertensive rats	[137]
	Rind	Garcinol, citric acid, and morelloflavone	Anti-obesity	Diet-induced metabolic syndrome in rats	[79]
	Pulp	Hydroxymethylfurfural and 3-methyl-2,5-furandione	Anticancer	MTT assay	[110]
	Pulp	Garcinol	Anti-inflammation	LPS-activated THP-1 and Raw 264.7 macrophages	[80]
	Rind	Garcinol	Hepatoprotective	Dimethylnitrosamine (DMN)-induced liver fibrosis in rats	[138]
G. indica	Rind	Garcinol	Anti-arthritic	Complete Freund's Adjuvant (CFA) induced arthritis in Wistar albino rats	[139]
	Rind	Naringenin, *p* and *o*-coumaric acid, and apigenin	Antioxidant	DPPH and FRAP assays.	[5]
G. humilis	Peel	Epicatechin, procyanidins, mangostanol, and γ-mangostin	Anti-melanoma	Cell Counting Kit-8	[18]
	Rind and pulp	Procyanidin B2 and citric acid	Cardioprotective	High carbohydrate and fat-fed male Wistar rats	[12]
G. latissima	Whole	6-Deoxyjacareubin	Antibacterial	Microdilution with thiazolyl blue tetrazolium bromide indicator	[51]
G. lanceifolia	Pulp	Quercetin, rutin, hesperidin, naringin, and gallic acid	Antioxidant	DPPH and ABTS assay	[135]
	Pulp	Quercetin and gallic acid	Anti-cancer	MTT assay	[135]
G. madruno	Epicarp	Morelloflavone and fukugiside	Antioxidant	ORAC and FRAP assay	[92]
G. mangostana	Pericarp	Gartanin, smeathxanthone, garcinone E, and γ-mangostin	Wound healing	Human gingival fibroblast cell cultures	[140]
	Peel	γ-mangostin	Anti-aging	Hyaluronidase and tyrosinase assays	[141]

Plant species	Plant part	Compounds	Activity	Experimental model	Reference
	Peel	α-mangostin	Antibacterial	Disc diffusion method	[142]
	Pulp and rind	Gallic acid, catechin, epicatechin, vanillic acid, trans-ferulic acid, rutin, γ and α-mongostins	Antioxidant	DPPH and ABTS assays	[63]
	Pericarp	β-Mangostin	Anti-tumor	C6 Glioma Cells	[143]
	Pericarp	4-Bromo-tetrahydro-α-mangostin and 1,3,6-trihydroxy-2-(2,3-dihydroxy-3-methyl butyl)-7-methoxy-8-isopentyl-9H-xan then-9-one	Cholinesterase	Cholinesterase assay	[67]
	Pericarp	α-mangostin	Anti-inflammation	Lipopolysaccharide-induced RAW 264.7 (from the ATCC) and carrageenan-induced peritonitis in mice	[130]
	Pericarp	Mangostanaxanthones (I and II)	Antioxidant	DPPH assay	[60]
	Pericarp	Mangostanaxanthones II, α-mangostin, and rubraxanthone	Antimicrobial	Agar diffusion against *A.fumigatus* and *B.cereus*	[60]
	Whole	Garcinone E	Antidiabetic	PTP1B activity assay	[55]
	Pericarp	Mangoxanthone A	Antidiabetic	α -glucosidase and α -amylase	[9]
	Pericarp	1,3,7-trihydroxy-2-(3-methyl-2-butenyl)-8-(3-hydroxy-3-methyl butyl)-xanthone, 1,3,8-trihydroxy-2-(3-methyl-2-butenyl)-4-(3-hydroxyl-3-methylbutanoyl)-xanthone, garcinone C and D, gartanin, xanthone I, and γ-mangostin	Anticancer	Colorimetric 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl-2*H*-tetrazolium bromide (MTT) assay	[62]
	Pericarp	γ-mangostin	Hepatoprotective	Tert-butyl hydroperoxide induced oxidative injury in HL-7702 cells	[53]
	Peicarp	7-O-Demethyl mangostanin	Anti-cancer	CNE-1, CNE-2, A549, H490, PC-3, SGC-7901 and U87 cells	[65]
	Pericarp	Garcinone E	Hepaprotective	Concanavalin A-induced mice	[115]
	Pericarp	α-Mangostin	Anti-urolithiatic	Ethylene glycol- induced Wistar albino rats	[144]
	Pericarp	Garcinone E, 1,3,6,7-tetrahydroxyxanthone, and garcinoxanthone U	Antioxidant	DPPH assay	[61]
	Pericarp	Garcinone E and 1,3,6,7- tetrahydroxyxanthone	Anticancer	Sulforhodamine B (SRB) assay	[61]
	Pericarp	α-Mangostin	Anti-inflammation	Nitric acid assay	[118]
	Aril	Mangostanin	Antioxidant	*In vitro* human epidermal keratinocytes	[64]
	Pericarp	α-Mangostin	Wound healing	Scratch assay	[118]
	Whole	α-Mangostin, β-mangostin, and 3-isomangostin	Antimalarial	Plasmodial lactate dehydrogenase assay	[81]
G. morella	Pericarp	Garcinol	Anticancer	Neuroblastoma cell line	[42]
G. nujiangensis	Whole	Nujiangefolin D	Anticancer	HeLa, PANC-1, and MDA-MB-231 cell lines	[145]
	Whole	Isojacareubin	Antitumor	Human OC cells HEY and ES-2	[52]
G. oblongifolia	Whole	Garcoblone F	Anticancer	Nasopharyngeal carcinoma (NPC) cell lines	[6]
G. pedunculata	Pericarp	Pedunxanthone D	Anticancer	SRB assay	[69]
	Pulp and rind	Hydroxycitric acid, hydroxycitric acid lactone, parvifoliquinone, GB-1a, garcinone A, 9- hydroxycalabaxanthone, chlorogenic acid, and garcinol	Cardioprotective	Isoproterenol-induced cardiac infarction in Winstar rats	[70]
G. schomburgkiana	Whole	Schomburgkianone (A, B, D and E), gutiiferone K, oblingifolin C and garciyunnanin A	Anticancer	HeLa human cervical cancer cells	[84]
G. speciosa	Whole	Garciosaterpenes D, E and F	Anti-HIV	Anti-HIV-1 reverse transcriptase assay	[103]
	Whole	Garciosaterpenes D, wallichinanes A and E	Anti-inflammation	Phenylpropiolate (EPP)-induced ear edema	[103]

Plant species	Plant part	Compounds	Activity	Experimental model	Reference
G. xanthochymus	Pulp	Isoxanthochymol, xanthochymol, guttiferone E, and cycloxanthochymol	Antitumor	HepG2 and MCF-7 cell lines, and H22 allograft mouse mode	[28]
	Seed	Garxanthochin B	Anticancer	HL-60, A549, SMMC-7721, MDA-MB-231, and SW480 cell lines	[88]
	Whole	Garcixanthochymone G and 7-epi- cycloxanthochymol	Anticancer	MTT assay using HepG2, A549, SGC7901, and MCF-7 cell lines	[89]
	Pulp	Garcixanthochymones (A-E)	Anticancer	Human tumor cell lines (HepG2, A549, SGC7901, MCF-7)	[1]
	Whole	Xanthochymol	Antifungal	Fungal apoptosis against *C. albicans*	[90]
	Aril and pericarp	Amentoflavone and fukugetin	Anti-angiogenic	Zebrafish angiogenesis assay	[44]
	Whole	Garcinoxanthocins A and B, 14-deoxygarcinol, xanthochymol, garcicowin, isogarcinol, and cycloxanthochymol	Anticancer	Glioma and MDA-MB-231 cancer cells	[85]
	Whole	Guttiferone (E and H) and isoxanthochymol	Antimalarial	Plasmodial lactate dehydrogenase assay	[81]
	Pulp	2,4,6,3′,4′-pentahydroxybenzophenone-2-O-β-D-glucopyranoside	Anti-inflammatory	Nitric Oxide (NO) production assay and IL-6 assay	[86]
G. yunnanensis	Whole	Garciyunnanins C and D	Antibacterial	Western blotting assay	[91]

An earlier report by different researchers on the same species disclosed that 2,4,6,3`,4`,6`-hexahydroxybenzophenone, 6-O-β-D-glucopyranosy-2,4,6,3`,4`,6`-hexahydroxybenzophenone and [2R,3R-5,7-dihydroxy-8- C-β-D-glucopyranosyl-4`-methoxy-2,3-dihydroflavon-3-ol exhibited significant antioxidant activity with IC_{50} values of 21.6, 43.5, and 36.4 µg/mL, respectively in comparison to butylated hydroxyanisole (IC_{50} = 26.3 µg/mL) [4]. The methanolic extracts of *G. lanceifolia* possess high potency for scavenging properties with IC_{50} values of 78 and 81 µg/mL in DPPH and 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid (ABTS) assays, respectively [135]. The biological activities of the isolated bioactive compounds from *Garcinia* fruit species are summarized in Table 11.

8. Conclusion

This review provides an account of *Garcinia* fruits' phytochemical constituents and biological properties. The fruits are rich in primary (vitamins, proteins, minerals, and carbohydrates) and secondary metabolites (xanthones, benzophenones, flavonoids, anthocyanins, and terpenoids). The isolated secondary metabolites from the fruits have a wide range of biological and pharmacological activities including anti-inflammatory, anti-allergy, antitumor, anti-obesity, anti-HIV, antifungal, antioxidant, anti-plasmodial, antimicrobial, and antidiabetic *in vitro* and *in vivo* models. Detailed information on the bioactive compounds of the valuable *Garcinia* fruits can promote their cultivation, utilization, and commercialization.

Scientific evidence from different researchers points out that the fruits are good sources of bioactive compounds for dietary supplements and for nutraceutical and therapeutic purposes. Many species are unexplored despite being rich in bioactive compounds and biological activities. Much work has focused on a few species that are already on the market. Furthermore, more scientific data is available on the non-fruit parts of the *Garcinia sp*. In addition, studies on the biological activities of the fruit extracts and their mechanism of action are limited. Further research is required to understand the mechanism by which these bioactive compounds exert their effect. Such information will promote the use, value addition, and commercialization of different *Garcinia* fruits.

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Conflicts of Interest

The authors declare no conflict of interest.

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