Bioactive Compounds from *Garcinia* Fruits of High Economic Value for Food and Health

55

Hosakatte Niranjana Murthy, Vijayalaxmi S. Dandin, Dayanand Dalawai, So-Young Park, and Kee-Yoeup Paek

Contents

H. N. Murthy (✉)
Department of Botany, Karnatak University, Dharwad, India

Research Center for the Development of Advanced Horticultural Technology, Chungbuk National University, Cheongju, Republic of Korea
e-mail: nmurthy60@yahoo.co.in

V. S. Dandin · D. Dalawai
Department of Botany, Karnatak University, Dharwad, India
e-mail: vijayalaxmidandin@gmail.com; dayananddalawai@gmail.com

S.-Y. Park · K.-Y. Paek
Research Center for the Development of Advanced Horticultural Technology, Chungbuk National University, Cheongju, Republic of Korea
e-mail: soypark7@chungbuk.ac.kr; cbnbio@hotmail.com

J.-M. Mérillon, K. G. Ramawat (eds.), *Bioactive Molecules in Food*, Reference Series in Phytochemistry, https://doi.org/10.1007/978-3-319-78030-6_65

Abstract

Garcinias (Mangosteen, Brindle berry, and Kokum) are tropical fruits, and are rich source of nutrients, minerals, vitamins, and dietary fibers. They are also abundant with bioactive compounds namely xanthones, benzophenones, hydroxycitric acid, and anthocyanins. Many studies have detailed that these compounds possess antioxidant, anti-inflammatory, anticancer, antimicrobial, antiallergy, antiulcer, antiparasitic, and antihelminthic activities to aid in human health and also weight loss and appetite-reducing properties, making them good dietary supplements. Therefore, bioactive compounds extracted from Garcinia fruits could be used in the preparation of pharmaceuticals and nutraceuticals. This review presents an overview of the bioactive compounds derived from Garcinia fruits and their biological activities for promoting human health as food and drug.

Keywords

Brindle berry · *Garcinia* · Garcinol · Hydroxycitric acid · Kokum · Mangosteen

1 Introduction

Garcinias are important tropical fruits naturally occurring in Asia, Africa, South America, Australia, and Polynesia. Mangosteen (Botanical name; *Garcinia mangostana* L.), Brindle berry [Botanical name: *Garcinia gummigutta* (L.) N. Bobson. Syn. *G. cambogia* (Gaertn.) Desr.], and Kokum (Botanical name: *Garcinia indica* Choisy) are main fruit yielding trees cultivated in different regions of the world including Australia, Cuba, Dominica, Ecuador, Gabon, Ghana, Guatemala, Honduras, India, Jamaica, Liberia, Myanmar, Nepal, Philippines, Puerto Rico, Singapore, Sri Lanka, Thailand, Trinidad and Tobago, United States of America, Vietnam, and Zanzibar [1]. The fruits of Garcinias with medicinal and neutraceutical properties have been used since ancient times in traditional medicinal practices. The progress and promise in advanced technology for isolation of the bioactive compounds from plants was vital in preferring the synthetic products from the fruits of these plants for pharmacological treatment as it could help in structural modifications of the plant-derived compounds to produce potentially more active and safer drugs and also in improving the economy of pharmaceutical industries. The rind and fruit pulp of mangosteen, brindle berry, and kokum are the rich sources of compounds like xanthones, benzophenones, anthocyanins, and hydroxycitric acid which are proved to be the plant drugs demonstrating a large array of biological activities. Fruit pulp of these plants is rich in nutrients, minerals, vitamins, and dietary fibers. Hence, the Garcinia fruits serve as pools of nutrients as well as medicinal drugs to aid in human health.

2 Fruit Description and Traditional Medicinal Uses of *Garcinia* Fruits

Mangosteen, brindle berry, and kokum fruits are used in traditional medicine in Asian countries as folk medicine or herbal medicine to treat various ailments. Juice extracted from the entire fruit or extract obtained from the pericarp (rind) along with arils (pulp) or dried powdered rind (Fig. 1) is used in the preparation of drugs in Indian, Chinese, Thai, and Malaysian system of medicine.

2.1 Fruit Description and Traditional Uses of Mangosteen

Mangosteen fruits are round, red to purplish in color, soft, juicy with sweet flavor, and pleasant aroma, therefore, mangosteen fruits are popularly known as "Queen of fruits" (Fig. 2a) [2]. The pericarp or rind is rich in pigments especially anthocyanins (Fig. 2b). The arils (edible parts) are white, juicy, sweet, and acidic (Fig. 2c) [3]. Mangosteen fruit rinds are used in the treatment of dysentery, ulcers, skin infections, wound and as an astringent, antimicrobial, and antiparasitic agent in China, India, and Thailand [4–9]. The rind decoction is utilized to relieve diarrhea, cystitis, gonorrhea, and gleet [4, 7, 10].

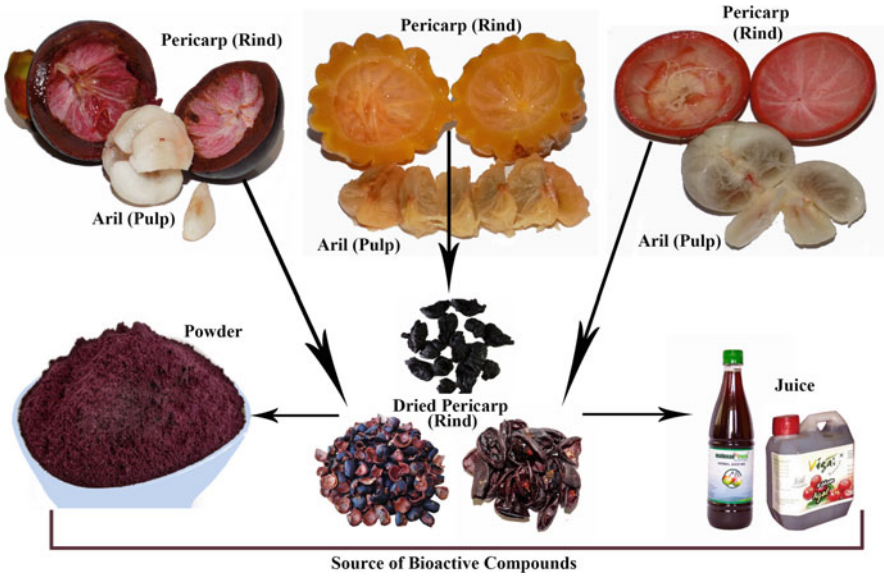


Fig. 1 Fruits, dried pricarp (rind), powdered pericarp and juice of mangosteen, bridle berry, and kokum used as a source of bioactive compounds

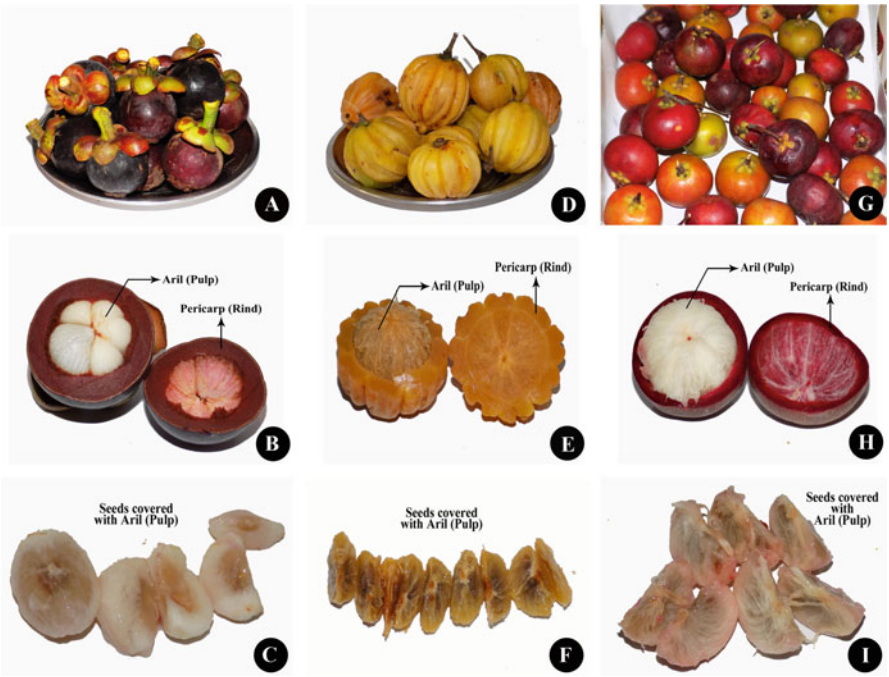


Fig. 2 Fruits of *Garcinia* species. (**a**) Fruits of mangosteen; (**b**) Cross section of mangosteen fruit showing aril and pericarp; (**c**) Arils of mangosteen; (**d**) Fruits of brindle berry; (**e**) Cross section of brindle berry fruit showing aril and pericarp; (**f**) Arils of brindle berry; (**g**) Fruits of kokum; (**h**) Cross section of kokum fruit showing aril and pericarp; (**i**) Arils of kokum

2.2 Fruit Description and Traditional Uses of Brindle Berry

Brindle berry fruits are small, about 5 cm in diameter with 6–8 grooves yellow or red in color (Fig. 2d, e). Arils are whitish to yellow (Fig. 2f). The fruits are edible, acidic and dried fruit rind is used as condiment. Fruits are also rich source of hydroxycitric acid which is an antiobesity drug [11]. Brindle berry fruits are edible; the rind is dried and used as condiment in India and Sri Lanka [1, 11]. The juice or powdered rind is used in traditional medicine to treat rheumatism and bowel problems. Rind preparations are used as purgative, hydragogue, antihelminthic and emetic [12].

2.3 Fruit Description and Traditional Uses of Kokum

Kokum fruits are round or oval, yellow to purple in color (Fig. 2g–i). The fruits are used in the preparation of juice which is used as a coolant and dried rinds are used as condiment (Fig. 1). Mangosteen, brindle berry, and kokum fruits are rich in nutrients, minerals, vitamins, and dietary fibers [13–15]. Kokum fruits are edible, delicious, and have a pleasant flavor and sour taste. Fruits are used in making health beverages

or squash and jellies. The dried rinds of Kokum are used as acidulant and preservative in Indian dishes [16]. The fruit juice is used as a coolant, and is beneficial to cure stomach and liver disorders. Kokum is also found to be effective in treatment of dysentery, tumors, and heart complaints [4, 17].

3 Bioactive Compounds Isolated from *Garcinia* Fruits

3.1 Bioactive Compounds Isolated from Mangosteen Fruits

The major bioactive compounds in mangosteen, brindle berry, and kokum fruits are xanthone derivatives [2, 18]; benzophenone derivatives [4, 19]; and anthocyanins [4]. Xanthones are secondary metabolites which belong to the polyphenolic group consisting of tricyclic aromatic ring. Xanthones are classified into five groups namely simple oxygenated xanthones, xanthone glycosides, prenylated xanthones, xanthonolignoids, and miscellaneous xanthones [20]. Mangosteen fruits consist of xanthones which have substituted isoprene, phenolic, and methoxy groups. α-mangostin was first isolated by Schmid [21] from mangosteen fruits and its chemical nature was elucidated by Dragendorff [22]. More than 54 xanthone derivatives have been isolated from mangosteen fruit till now (Table 1). Major benzophenones isolated are garcimangosone D, maclurin, kolanone [4]. Chrysanthemin, cyanidin-3-*O*-glucoside, cyanidin-3-*O*-sophoroside are the anthocyanins extracted from fruits of mangosteen (Table 1) [4].

3.2 Bioactive Compounds Isolated from Brindle Berry Fruits

The important phytochemicals reported from brindle berry fruits are organic acids, xanthones, and benzophenones (Table 2). Hydroxycitric acid (HCA) is the major organic acid isolated from the fruit of brindle berry and the concentration of HCA ranges from 10% to 13% [11, 48]. HCA lactone or Garcinia lactone was also obtained along with HCA from fruits [51]. Major xanthones isolated from fruits of brindle berry are polyisoprenylated xanthones, i.e., oxy-guttiferone I, oxy-guttiferone K, oxy-guttiferone K2, and oxy-guttiferone M (Table 2) [52]. Guttiferone I, guttiferone N, guttiferone J, guttiferone K, and guttiferone M were the polyisoprenylated benzophenones isolated from fruits of brindle berry [52].

3.3 Bioactive Compounds Isolated from Kokum Fruits

The principal phytochemicals isolated from kokum fruits with proven biological activity are hydroxycitric acid, benzophenone derivatives, and anthocyanins (Table 3). Kokum fruit contains polyisoprenylated benzophenone derivatives such as garcinol (camboginol/guttiferone E), isogarcinol (cambogin), xanthochymol,

Table 1 Compounds isolated from fruit of mangosteen

Xanthones	References
α-mangostin	[2, 19, 23–35]
β-mangostin	[19, 24, 25, 27, 30, 31, 35]
γ- mangostin	[2, 19, 23, 24, 27, 30, 31, 33, 34, 36, 37]
1,2-dihydro-1,8,10-trihydroxy-2-(2-hydroxypropan-2-yl)-9-(3-methylbut-2-enyl) furo[3,2-a]xanthen-11-one	[32]
1,3,6,7-tetrahydroxy-2,8-(3-methyl-2-butenyl) xanthone	[9]
1,3,6,7-tetrahydroxy-8-(3 methyl-2-butenyl)-9H–xanthon-9-one	[19]
1,3,6-trihydroxy-7-methoxy-2,8-(3-methyl-2-butenyl) xanthone	[9]
1,3,7-trihydroxy-2,8-di-(3-methylbut-2-enyl) xanthone	[31, 32]
1,5-dihydroxy-2-(3-methylbut-2-enyl)-3-methoxy-xanthone	[19, 30]
1,5-dihydroxy-2-isopentyl-3-methoxy xanthone	[4]
1,6-dihydroxy-7-methoxy-8-isoprenyl-6,6-dimethylpyrano (2,3:3,2) xanthone	[25, 26]
1,7-dihydroxy-2-(3-methylbut-2-enyl)-3-methoxy-xanthone	[19, 24, 26, 30]
1,7-dihydroxy-2-isopentyl-3-methoxy xanthone	[4]
11-hydroxy-1-isomangostin	[25]
1-isomangostin hydrate	[31]
1-isomangostin	[2, 19, 31]
2-(γ, γ-dimethylallyl)-1,7-dihydroxy-3-methoxyxanthone	[31, 33]
2,7-di-(3-methy-but-2-enyl) -1,3,8-trihydroxy 4-methylxanthone	[38]
2,8-di-(3-methy-but-2-enyl)-7-carboxy-1,3 dihydroxyxanthone	[38]
3-isomangostin hydrate	[31]
3-isomangostin	[19, 31]
5,9-dihydroxy-8-methoxy-2,2-dimethyl-7-(3-methylbut-2-enyl)-2H,6H–pyrano-[3,2,6]-xanthene-6-one	[19, 33, 39]
6-deoxy-7-demethylmangostanin	[32]
8-deoxygartanin	[2, 19, 25, 27, 33, 40]
8-hydroxycudraxanthone G	[2]
BR-xanthone A	[41]
BR-xanthone B	[41]
Calabaxanthone	[31]
Cudraxanthone G	[2]
Demethylcalabaxanthone	[26, 31]
Garcimangosone A	[19]
Garcimangosone B	[2, 19]
Garcimangosone C	[19]
Garcinone A	[42]
Garcinone B	[19, 25, 26, 35, 42]
Garcinone C	[25, 42]
Garcinone D	[2, 19, 25, 27, 43]
Garcinone E	[2, 19, 24, 25, 30, 33, 34, 44]
Gartanin	[2, 19, 25, 27, 30, 31, 33, 40]

(*continued*)

Table 1 (continued)

Xanthones	References
Mangostanin	[25, 26, 32]
Mangostanol	[19, 25, 26, 33, 35]
Mangostenol	[26, 35]
Mangostenone A	[26, 35]
Mangostenone B	[35]
Mangostenone C	[25]
Mangostenone D	[25]
Mangostenone E	[25]
Mangostingone	[2]
Mangostinone	[2, 24–26, 30, 35]
Smeathxanthone A	[2]
Thwaitesixanthone	[25]
Tovophyllin A	[2, 19, 34]
Tovophyllin B	[19, 26, 35]
Trapezifolixanthone (Toxyloxanthone A)	[26, 35]
Benzophenones	
Garcimangosone D	[19, 45]
Kolanone	[4]
Maclurin	[4]
Anthocyanins	
Chrysanthemin	[4]
Cyanidin-3-*O*-glucoside	[46]
Cyanidin-3-*O*-sophoroside	[46]
Pelargonidin 3-glucoside	[47]

Table 2 Compounds isolated from fruit of brindle berry

Organic Acids	References
Hydroxycitric acid	[48–50]
Garcinia lactone (HCA lactone)	[51]
Xanthones	
Oxy-guttiferone I	[52]
Oxy-guttiferone K	[53]
Oxy-guttiferone K2	[52]
Oxy-guttiferone M	[52]
Benzophenones	
Garcinol	[54]
Guttiferone I	[53]
Guttiferone J	[53]
Guttiferone K	[53–55]
Guttiferone M	[53, 55]
Guttiferone N	[53]

Table 3 Compounds isolated from fruit of kokum

Organic Acids	References
Hydroxycitric acid	[56]
Garcinia lactone (HCA lactone)	[56]
Benzophenones	
Garcinol	[57]
Isogarcinol	[57]
Xanthochymol	[58]
Isoxanthochymol	[58]
Anthocyanins	
Cyanidin-3-*O*-glucoside	[15, 59, 60]
Cyanidin-3-sambubioside	[15, 59, 60]

isoxanthochymol [56, 61]. Kokum fruit is also rich in anthocyanin namely cynidin-3-glucoside and cynidin-3-sambubioside [15].

4 Biological Activities of Compounds Obtained from *Garcinia* Fruits

4.1 Biological Activities of Xanthones

The most abundant xanthones in the mangosteen fruits are α-mangostin and γ-mangostin, and among these α-mangostin is reported to have antioxidant, anti-inflammatory, anticancer, and antimicrobial activities [62–65].

4.1.1 Antioxidant Activity

α-mangostin was reported to be a potent antioxidant and it was demonstrated to reduce copper/peroxyl radical induced oxidation of human low density lipoproteins [66, 67]. Jung et al. [2] showed optimal $ONOO^-$ scavenging activity of α-mangostin in mouse mammary organ cultures. Sampath and Vijayaraghavan [68] studied the impact of α-mangostin on the antioxidant defiance system and lipid peroxidation against isoproterenol-induced myocardial infarction in rats. Induction of rats with isoproterenol (150 mg kg^{-1}) for 2 days resulted in marked elevation of lipid peroxidation enzymes in the serum namely creatine phosphokinase (CPK), lactate dehydrogenase (LDH), glutamate pyruvate transaminase (GPT), and glutamate oxaloacetate transaminase (GOT) and remarkable decrease in various antioxidant enzymes such as glutathione-S-transferase (GST), glutathione peroxidase (GPX), catalase (CAT), superoxide dismutase (SOD), and glutathione (GSH). Pretreatment of α-mangostin (200 mg kg^{-1}) orally for 6 days prior to isoproterenol administration and 2 days along with isoproterenol administration substantially attenuated such changes.

The renoprotective effect of α-mangostin on cisplatin-induced nephrotoxicity in rats was reported by Perez-Rojas et al. [69]. For 10 days 12.5 mg kg^{-1} day^{-1} of α-

mangostin was administered to experimental rats and on the seventh day the rats were treated with a single dose of cisplatin (7.5 mg kg^{-1}). After 3 days, the rats were killed and studied for the impact of α-mangostin. The attenuation of renal dysfunction, oxidative/nitrosative stress, and structural damages was recorded. The preventive effect of α-mangostin on cisplatin-induced apoptic death is attributed to the inhibition of p53 expression and reactive oxygen species generation. Similarly, the protective effect of α-mangostin on cardiac reperfusion damage was investigated by Buelna-Chontal et al. [70]. Their findings show that α-mangostin could maintain the mechanical work of the heart, decrease the area of infarct, and even prevent the decrease in cardiac ATP and phosphocreatine levels in reperfused myocardium. The defensive effect of α-mangostin was related with reduction in oxidative stress. α-mangostin treatment was found to prevent reperfusion injury-induced protein oxidation, and reduction of glutathione content and lipid peroxidation.

4.1.2 Anti-Inflammatory and Antiallergic Activity

Alpha-mangostin was reported to have potent anti-inflammatory and antiallergic effects [23, 71–73]. Chen et al. [23] studied the effect of α-mangostin on the murine macrophage cell line RAW 264.7 and reported the inhibition of nitric oxide (NO) and prostaglandin E2 (PGE_2) production. At 3–25 μM α-mangostin, the amount of NO production was measured continuously and the IC_{50} value was 12.4. The production of PGE_2 in lipopolysaccharide-activated RAW 264.7 cell was also significantly reduced by α-mangostin (IC_{50} value of 11.08 μM). Chen et al. [23] also verified induction of nitric oxide synthase (iNOS) and expression of cyclooxygenase (COX) enzyme to investigate the effect of α-mangostin. α-mangostin concentration was found to reduce iNOS induction in a concentration-dependent manner. 1 μg ml^{-1} lipopolysaccharide was used to activate the RAW 264.7 cells for 12 h and nitric oxide synthase activity in the activated RAW 264.7 macrophages was inhibited following 24-h treatment of 5 μg ml^{-1} α-mangostin.

A study conducted by Chae et al. [73] to investigate the effect of α-mangostin and γ-mangostin on the bone marrow-derived mast cell (BMMC) mediated allergy mechanism induced by phorbol 12-myristate 13-acetate (PMA) plus calcimycin A23187. Both α-mangostin and γ-mangostin were shown to inhibit the production of interleukin-6 (IL-6), prostaglandin D2 (PGD2), and leukotriene C4 (LTC4) and degranulation of BMMC induced by PMA plus calcimycin A23187. In addition, both α-mangostin and γ-mangostin were found to repress cyclooxygenase (COX-2) expression as assessed by reverse transcription polymerase chain reaction (RT-PCR) analysis. These results advocate the usefulness of α-mangostin and γ-mangostin in reduction of allergic inflammatory responses.

4.1.3 Anticancer Activity

The α-mangostin (as well as β- and γ-mangostin) was reported to possess inhibition of cell proliferation of human cancer cells [74]. The antiproliferative effects of α-, β-, γ-mangostin were associated with cell-cycle arrest by affecting the expression of cyclins, cdc2, and p27. α- and γ-mangostin were found to induce apoptosis of cancer cells through G1 and S arrest by the activation of intrinsic pathway following the

downregulation of signaling pathways involving MAP kinases and serine/threonine kinase activities.

Matsumoto et al. [24] conducted a study on the inhibitory effects of α-mangostin, β-mangostin, γ-mangostin, mangostinone, garcinone E, and 2-isoprenly-1, 7-dihydroxy-3-methoxyxanthone on cell growth of the human leukemia cell line HL60, K562, NB4, and U937. α-mangostin was found to be potent at 10 μM concentration and exhibited the highest inhibitory activity compared to other xanthones. Matsumoto et al. [75] also studied antiproliferative effects of α-, β-, γ-mangostin and methoxy-β-mangostin on human cancer DLD-1 cells. Their results showed that α-mangostin strongly suppressed cell growth at 20 μM, and these effects were associated with cell-cycle arrest by affecting cyclins, cdc2, and p27 expression.

Sato et al. [10] examined the effect of α-mangostin on PC12 rat pheochromocytoma cells and the results showed apoptosis of cells through DNA fragmentation and caspase-3 cleavage. α-mangostin also exhibited features of the mitochondrial apoptotic pathway, including mitochondrial membrane depolarization. Besides, α-mangostin inhibited the endoplasmic reticulum Ca^{2+}-ATPase and activated c-Jun NH2 terminal kinase (JNK) which depicts endoplasmic reticulum stress. These results suggest that α-mangostin inhibits Ca^{2+}-ATPase to accomplish apoptosis of PC12 cells through the mitochondrial pathway.

Suksamrarn et al. [25] studied the effect of 19 xanthones on human breast cancer (BC-1), epidermoid carcinoma of the mouth (KB), and small cell lung cancer (NCI-H187) cell lines and reported that α-mangostin was found to be the most potent biochemical with an IC_{50} value (0.92 μg ml^{-1}) followed by gacinone E and γ-mangostin. Similarly, Kurose et al. [76] conducted a study on the effect of α-mangostin on the human breast cell line MDA-MB231 and described the apoptosis of these cell lines. They also reported significant cytochrome-c release with α-mangostin treated cell lines which suggested that MDA-MB231 cell line apoptosis occurred through the mitochondrial pathway. Their study also revealed that α-mangostin treatment induces cell cycle arrest though upregulation of the cyclin-dependent kinase (CDK) inhibitor $p21^{cip1}$ and cell cycle checkpoint regulator CHEK2 [76].

Hung et al. [77] evaluated the antimetastatic effect of α-mangostin against human prostrate carcinoma cell line PC-3 and reported the decreased expression of multiple matrix degrading proteinases including matrix metalloproteinase-2 (MMP-2), matrix metalloproteinase-9 (MMP-9), and urokinase-plasminogen activator (u-PA). α-mangostin also inhibited the phosphorylation of c-JUN N-terminal kinase 1 and 2 (JNK1/2) as well as activation of nuclear factor kappa B (NF-kB), oncogene c-Fos and c-Jun, which are associated with invasion and metastasis of cancer cells. Similar results were also recorded when human melanoma cell line SK-MEL-28 and squamous cell carcinoma cell line A-431 were treated with α-mangostin [78].

In a study, Aisha et al. [79] verified the effect of α-mangostin and γ-mangostin on colon cancer cell line HCT 116, and their study revealed that these xanthones showed strong cytotoxicity through induction of the mitochondrial apoptosis pathway. In addition, α-mangostin and γ-mangostin was found to inhibit cell

migration, invasion, and clonogenicity, which are the major steps in tumor metastasis.

4.1.4 Antimicrobial Activity

Xanthones isolated from fruits of *Garcinia* species especially α-mangostin and γ-mangostin have been shown to exhibit antimicrobial activity against a range of pathogens including bacteria, fungi, and viral species [26, 80–84]. Sundaram et al. [85] studied the effect of α-mangostin on majority of bacterial and fungal species including *Streptococcus aureus*, *Pseudomonas aeruginosa*, *Salmonella typhimurium*, *Bacillus subtilis, Klebsiella* sp., *Proteus* sp., *Escherichia coli*, *Epidermophyton floccosum*, *Alternaria solani*, *Mucor* sp., *Rhizopus* sp., *Cunninghamella echinulata*, *Trichophyton mentagrophytes*, *Microsporum canis*, *Aspergillus niger*, *Aspergillus, flavus*, *Penicillium sp*., *Fusarium roseum*, and *Curvularia lunata*. The minimum inhibitory concentration of α-mangostin was between 1.25–50 μg ml^{-1} for bacteria and 1–5 μg ml^{-1} for fungi, respectively. Various scientists [62, 81] evaluated the effect of α-mangostin against Methicillin-resistant *Staphylococcus aureus* (MRSA) and results revealed that minimum inhibitory values ranging between 1.57–12.5 μg ml^{-1}. Gopalakrishnan et al. [27] demonstrated the potentiality of α-mangostin against phytopathogenic fungi, *Fusarium oxysporum vasinfectum*, *Alternaria tenuis*, and *Drechslera oryzae*.

HIV-1 protease activity of α-mangostin was demonstrated by Chen et al. [86] by using pepstatin-A as a positive control and α-mangostin exhibited an IC_{50} value of 5.12 μM. Kaomongkolgit et al. [87] discovered the inhibitory activity of α-mangostin against microorganism involved in oral-candidiasis, *Candida albicans*. They showed that α-mangostin was effective (at a minimum inhibitory concentration of 1000 μg ml^{-1}) when compared to clotrimazole and nystatin (antifungal medicines). Therefore, α-mangostin could be promising agent for the treatment of oral candidiasis. All the above investigations indicated the antimicrobial properties of α-mangostin.

4.1.5 Antiparasitic and Antihelminthic Activity

Various studies have shown that α-mangostin has insecticidal properties against dipteran, coleopteran, and hemipteran pests [88–90]. Ee et al. [88] discovered the inhibitory effect of α-mangostin on *Aedes aegypti* larval growth [lethal concentration (LC_{50}) was found to be 19.4 μg ml^{-1} for 24 h]. Kim and Lan [91] studied the larvicidal activities of α-mangostin using larvae and adults of the Colorado potato beetle, *Leptinotarsa decemlineata*. Their results reveal that α-mangostin had larvicidal activity at LC_{50} concentration of 63.33, 6.27, and 4.09 mM for 7-, 14-, and 23-day treatment, respectively. In addition, Bullangpoti et al. [92, 93] demonstrated the efficacy of α-mangostin against weevil (*Sitophilus oryzae*) and the brown plant hopper (*Nilaparvata lugens*), suggesting that α-mangostin inhibits esterase, acetyl cholinesterase, and glutathione *S*-transferase activities. Larson et al. [90] also demonstrated the larvicidal activities of α-mangostin in *Anopheles stephensi, Anopheles gambiae,* and *Culex pipiens, Anopheles aegypti* (Orlando strain), *Anopheles quadrimaculatus* Say, and *Culex quinquefasciatus* Say.

Keiser et al. [94] studied antihelmenthic effects of α-mangostin against trematodes *Schistosoma mansoni*, *Echinostoma caproni*, *Fasciola hepatica*, and the nematodes *Heligmosomoides polygyrus*, *Ancylostoma ceylanicum*, and *Trichuris muris*. Lack of activity of α-mangostin was recorded against *Heligmosomoides polygyrus* (third-stage larvae), *Ancylostoma ceylanicum* (third-stage larvae), and *Trichuris muris* (adults). A low activity was observed against *Ancylostoma ceylanicum* (adults; IC_{50} of 91 μg ml^{-1}), whereas promising activities were revealed against *Schistosoma mansoni*, *Echinostoma caproni*, *Fasciola hepatica* in vitro (IC_{50} value of 2.9–15.6 μg ml^{-1}). Worm burden reductions, ranging from 0% to 38% against *Schistosoma mansoni* and 11 to 54% against *Echinostoma caproni* were attained by single oral dose of the drug (400 mg kg^{-1} and 800 mg kg^{-1}) in vivo. The above investigations suggest that α-mangostin could be used as organic larvicidal and antihelminthic agent.

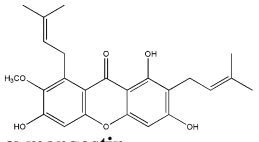
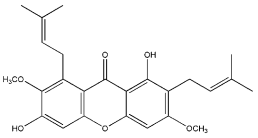
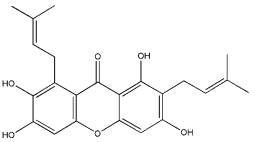
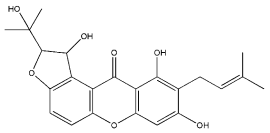
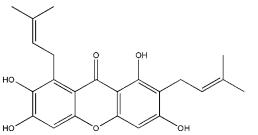
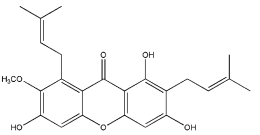
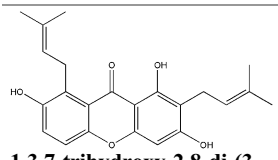
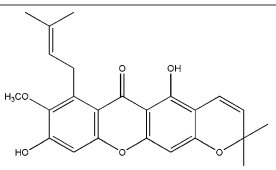
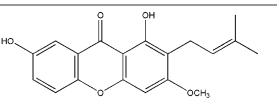
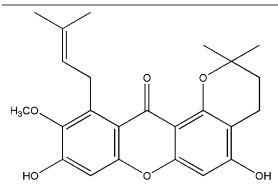
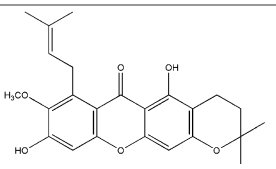
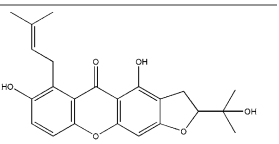
4.2 Biological Activity of Benzophenones

Natural benzophenones are a class of compounds having phenol-carbonyl-phenol skeleton. The A-ring is benzene ring which is derived from shikimic acid pathway, whereas B-ring is derived from acetate-malonate pathway, and undergoes prenylation and cylization producing a variety of compounds. Various numbers of –OH, OMe, prenyl, and geranyl groups are added as side chains [95]. Various polyisoprenylated benzophenones are reported from fruits of *Garcinia* species. Garcimangosone D, kolanone, and maclurin were isolated from fruits of mangosteen (Table 1) [4, 19]. Garcinol, guttiferone I, guttiferone J, guttiferone K, guttiferone M, guttiferone N were isolated from fruits of brindle berry (Table 2) [53–55]. Whereas fruits of kokum possessed garcinol, isogarcinol, xanthochymol, isoxanthochymol compounds (Table 3) [57, 58]. All the benzophenones isolated from the fruits of mangosteen, brindle berry, and kokum were reported to possess strong biological activities (Tables 2, 3, and 4) and garcinol is a well-known compound in terms of its pharmacological properties (Tables 5 and 6).

4.2.1 Antioxidant Activity

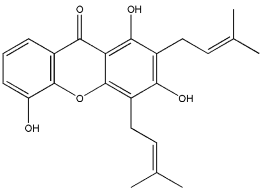
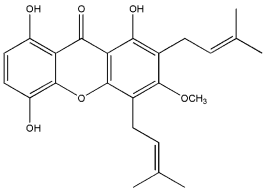
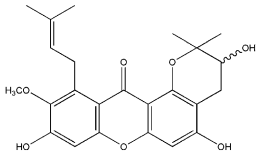
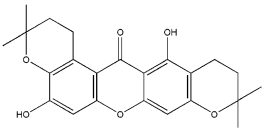
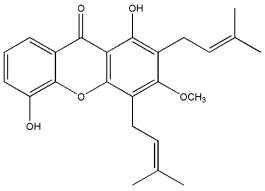
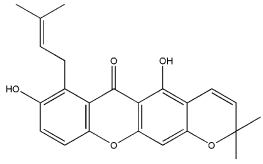
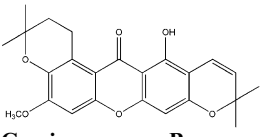
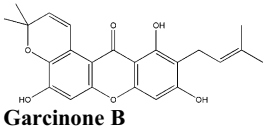
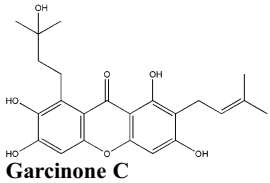
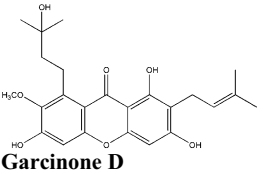
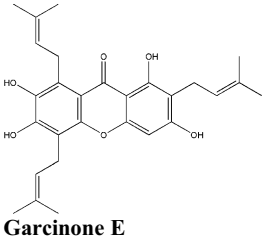
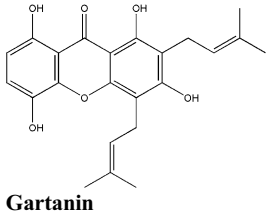
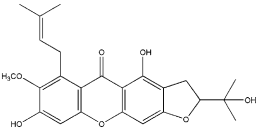
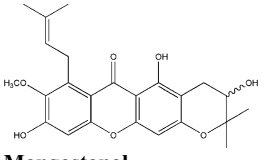
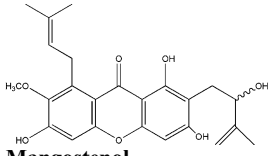
Garcinol exhibited a strong antioxidant activity against superoxide anion, hydroxyl radical, and methyl radicals. Yamaguchi et al. [96, 97] studied antioxidative, chelating, and free radical scavenging activities of garcinol and reported a moderate antioxidative activity in the micellar linoleic acid peroxidation system, while it exhibits nearly three times greater free radical scavenging activity against 2, 2, diphenyl-1-picrylhydrazyl (DPPH) radicals than the DL-α tocopherol (used standard chemical) by weight. These authors also recorded superoxide anion scavenging activity of garcinol and suppression of protein glycation in bovine serum/fructose system. Hong et al. [98] investigated a possible mechanism of antioxidant action of garcinol and its derivatives (cambogin, gracim-1, and gracim-2) on arachidonic acid metabolism and nitric oxide (NO) synthesis in lipoploysaccharide (LPS)-stimulated RAW264.7 cells. Results of this evaluation revealed that there was a significant

Table 4 Structure and biological activity of compounds obtained from mangosteen fruit

Xanthones		
 **α-mangostin** Biological activity: Anticancer, Anti-inflammatory, Antioxidant, Anti-obesity, Antimicrobial, Antihistamine, CNS depressant Activity, Antiulcer, Antituberculosis, Anti-allergy	 **β-mangostin** Biological activity: Anticancer, Antimicrobial, Antituberculosis	 **γ- mangostin** Biological activity: Anti-inflammatory, Antioxidant, Antimicrobial, Anticancer, Antihistamine, Antituberculosis, Anti-allergy
 **1, 2-dihydro-1,8,10-trihydroxy-2-(2-hydroxypropan-2-yl)-9-(3-methylbut-2 enyl)furo[3,2-a] xanthen-11-one** Biological activity: Antioxidant	 **1,3,6,7-tetrahydroxy-2,8-(3-methyl-2-butenyl) xanthone** Biological activity: Antioxidant	 **1,3,6-trihydroxy-7-methoxy-2,8-(3-methyl-2-butenyl) xanthone** Biological activity: Antioxidant
 **1,3,7-trihydroxy-2,8-di-(3-methylbut-2-enyl)-xanthone** Biological activity: Antioxidant	 **1,6-dihydroxy-7-methoxy-8-isoprenyl-6,6-dimethylpyrano(2,3:3,2) xanthone** Biological activity: Anticancer	 **1,7-dihydroxy-2-(3-methylbut-2-enyl)-3-methoxy-xanthone** Biological activity: Anticancer
 **1-isomangostin** Biological activity: Anti-inflammatory, Antimicrobial, Antioxidant, Anticancer	 **3-isomangostin** Biological activity: Antimicrobial	 **6-deoxy-7-demethylmangostanin** Biological activity: Antioxidant

(*continued*)

Table 4 (continued)

 **8-deoxygartanin** Biological activity: Anticancer, Antioxidant	 **8-hydroxycudraxanthone G** Biological activity: Antioxidant, Anticancer	 **11-hydroxy-1-isomangostin** Biological activity: Anticancer
 **BR-xanthone A** Biological activity: Antifungal	 **Cudraxanthone G** Biological activity: Anticancer, Antioxidant	 **Demethylcalabaxanthone** Biological activity: Antibacterial, Anticancer, Antituberculosis
 **Garcimangosone B** Biological activity: Antioxidant	 **Garcinone B** Biological activity: Antituberculosis	 **Garcinone C** Biological activity: Anticancer
 **Garcinone D** Biological activity: Antimicrobial, Anticancer, Antioxidant, Antituberculosis	 **Garcinone E** Biological activity: Anticancer, Antioxidant	 **Gartanin** Biological activity: Antioxidant, Antimicrobial, Anticancer
 **Mangostanin** Biological activity: Antioxidant, Antituberculosis, Anticancer	 **Mangostanol** Biological activity: Antituberculosis, Anticancer	 **Mangostenol** Biological activity: Antituberculosis

(*continued*)

Table 4 (continued)

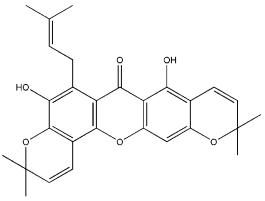
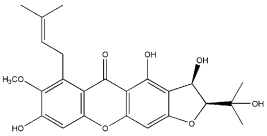
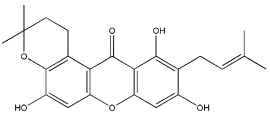
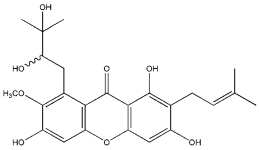
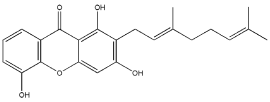
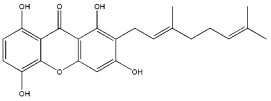
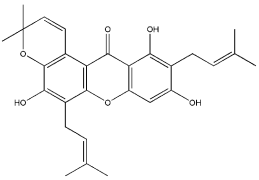
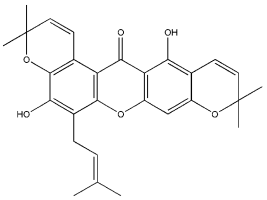
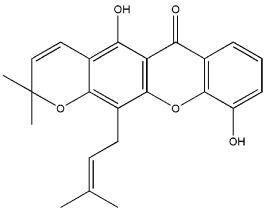
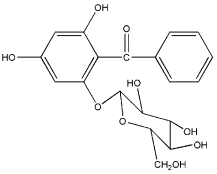
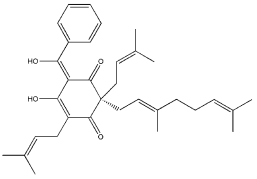
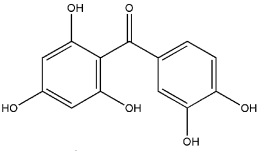
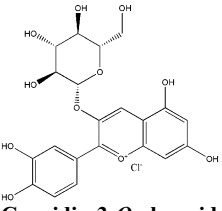
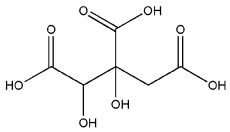
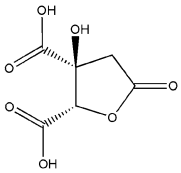
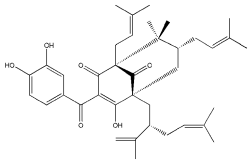
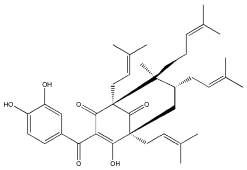
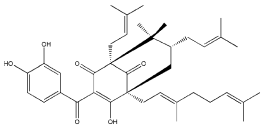
 **Mangostenone A** Biological activity: Antituberculosis	 **Mangostenone C** Biological activity: Anticancer	 **Mangostenone D** Biological activity: Anticancer
 **Mangostenone E** Biological activity: Anticancer	 **Mangostinone** Biological activity: Anticancer, Antituberculosis	 **Smeathxanthone A** Biological activity: Antioxidant
 **Tovophyllin A** Biological activity: Anticancer	 **Tovophyllin B** Biological activity: Antituberculosis	 **Trapezifolixanthone** Biological activity: Antituberculosis
Benzophenones		
 **Garcimangosone D** Biological activity: Inhibitor of pentosidine formation	 **Kolanone** Biological activity: Antimicrobial	 **Maclurin** Biological activity: Antioxidant
Anthocyanins		
 **Cyanidin-3-*O*-glucoside** Biological activity: Anti-inflammatory, Apoptosis inducer		

Table 5 Structure and biological activity of compounds obtained from brindle berry fruit

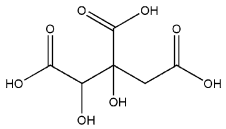
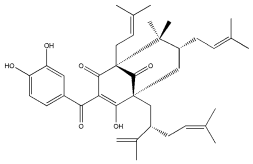
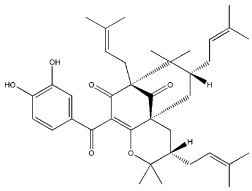
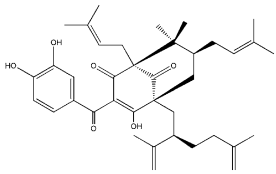
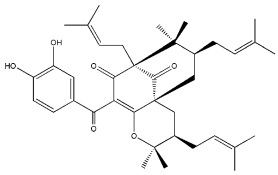
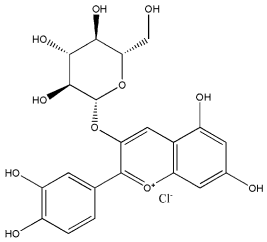
Organic Acids	
 **Hydroxycitric acid** Biological activity: Anti-obesity	 **Garcinia lactone (HCA lactone)** Biological activity: Anti-obesity
Benzophenones	
 **Garcinol** Biological activity: Antioxidant, Anticancer	 **Guttiferone K** Biological activity: Antioxidant, Anticancer
 **Guttiferone M** Biological activity: Anticancer	

inhibition to the release of arachidonic acid and it metabolizes in macrophages with the treatment of 1 mM garcinol and its derivatives to cell cultures after 1 h of LPS stimulation. Similar inhibitory activity of garcinol was also recorded by Hong et al. [98] in intestinal cell lines (HT-29, HCT-116, and IEC-6). Garcinol remarkably decreased inducible nitric oxide synthase (iNOS) express and nitric oxide (NO) release from LPS-stimulated macrophages. In another study, Sang et al. [99, 100] assessed the mechanism of antioxidant reactions of garcinol with a stable radical DPPH and characterized the reaction products. Depending on the position of hydroxyl group (C-3 or C-5) which initiates the reaction, different reaction products were formed (GDPPH-1 and GDPPH-2). Their study revealed that garcinol reacts with peroxyl radicals by a single electron transfer followed by deprotonation of the hydroxyl group from the enolized 1,3-diketone to form a resonance pair. The above investigations suggested that garcinol has potentiality as a free radical scavenger. Similar to garcinol, other benzophenones like xanthochymol, isoxanthchymol, guttiferone K, and maclurin are reported to possess excellent antioxidant activities [95].

4.2.2 Anti-Inflammatory Activity

Aberrant arachidonic acid metabolism and generation of nitric oxide were reported in lipopolysaccharide (LPS)-induced/stimulated inflammation in rat neuron cultures [98]. Archidonic acid is released by phospholipase A2 (cPLA2) from membrane phospholipids and is further metabolized by cyclooxygenase (COX), lipooxygenase (LOX) enzymes, and cytochrome P450 pathways. Cell cultures treated with garcinol (5 μM) showed modulation of archidonic acid metabolism through suppression of cytosolic PLA2 (cPLA2) and inhibition of extracellular ERK1/2 kinase activation

Table 6 Structure and biological activity of compounds obtained from kokum fruit

Organic Acids	
 **1. Hydroxycitric acid** Biological activity: Anti-obesity, Anti-inflammatory	
Benzophenones	
 **Garcinol** Biological activity: Antioxidant, Anti-inflammatory, Anticancer, Antiulcer, Antimicrobial, Gastroprotective	 **Isogarcinol** Biological activity: Anti-inflammatory, Anticancer, Antiulcer, Antiobesity, Antimicrobial
 **Xanthochymol** Biological activity: Antibacterial	 **Isoxanthochymol** Biological activity: Antibacterial
Anthocyanin	
 **Cyanidin-3-*O*-glucoside** Biological activity: Cardioprotective	

and suppression of iNOS expression through modulation of the janus kinase (JAK) pathway [98], and the results suggested the potent anti-inflammatory effects of garcinol. Similarly, Hung et al. [101] demonstrated the inhibitory effect of garcinol against 12–0-tetradecanoylphorbol 13-acetate (TPA)-induced skin inflammation in mice. Topical pre-treatment of mouse skin with garcinol remarkably reduced TPA-induced expression of inducible nitric oxide synthase and cyclooxygenase-2. In addition, garcinol markedly 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)/Akt, which are upstream of NF-κB. In addition, Koeberle et al. [102] demonstrated the significant effect of garcinol and its interference with two enzymes that play crucial role in inflammation, namely, 5-lipoxygense and microsomal prostaglandin PGE2 synthase (mPGES)-1. Garcinol was found to suppress 5-lipoxygense product formations in intact human neutrophils and reduced PGE2 formation of interleukin-1β-stimulated A549 human lung carcinoma cells and in human whole blood stimulated by lipopolysaccharide. Garcinol also hindered with isolated COX-1 enzyme (IC_{50} of 12 μM) and with formation of COX-1-derived 12(S)-hydroxy-5-cis-8, 10-trans-heptadecatrienoic acid and thromoxane B2 in human platelets [102].

4.2.3 Anticancer Activity

Various studies have examined the potential of benzophenones, especially garcinol, against different cancer types including breast cancer, colon cancer, pancreatic cancer, prostate cancer, lung cancer, leukemia, hepatocellular carcinoma. Tanaka et al. [103] carried out studies on the effect of garcinol on the development of azoxymethane (AOM)-induced colinic aberrant crypt foci (ACF) in F344 rats. In addition, this group also studied the effect of garcinol on proliferating cell nuclear antigen (PCNA) index in ACF and activities of detoxifying enzymes namely glutathione S-transferase (GST) and quinone reductase (QR) in liver. It was noticed that garcinol administration significantly reduced PCNA index in ACF and considerably elevated liver GST and QR activities. Further, garcinol was also found to suppress superoxide anion (O_2^-) and nitric oxide (NO) generation and expression of inducible nitric oxide synthase and cyclooxygenase-2 proteins. Liao et al. [104] studied the effects of garcinol in human colorectal cancer cell line HT-29 and showed the beneficial effects of tumor prevention. The cell lines treated with 10 μM garcinol inhibited cell invasion and decreased the tyrosine phosphorylation of focal adhesion kinase (FAK). Western blot analysis revealed that garcinol inhibits activation of the Src, MAPK/ERK, and P13K/Akt signaling pathways. In addition, the study also indicated that decreased metalloproteinase-7 (MMP-7) protein levels in HT-29 cells result in sensitization to garcinol and that the compound significantly inhibits the expression of metalloproteinase-7 (MMP-7) in IL-beta-induced HT-29 cells. Hong et al. [105] conducted a study to examine the effects of garcinol and its derivatives, cambogin, gracim-1, gracim-2, on the growth of HT-29 and HCT-116 colon cancer cells, as well as IEC-6 and INT-407 which are the normal immortalized intestinal cells. Garcinol and its derivatives showed strong growth-inhibitory effects on all intestinal cells, with IC_{50} values in the range of 3.2–21.4 μM after 72-h treatment. Garcinol was found to be more effective in inhibiting growth of cancer cells than normal immortalized cells. These observations suggest the possible chemopreventive role of garcinol.

Garcinol reported to possess a strong growth inhibitory activity in human leukemia HL-60 cells (IC_{50} of 9.42 μM) through the induction caspase-3 activity in a dose- and time-dependent manner and including degradation of poly (ADP-ribose) polymerase (PARP) protein [106]. Matsumoto et al. [24] examined the effects of garcinol, isogarcinol, and xanthochymol on cell growth in human leukemia cell

lines, U937, K562, NB4, and HL60 and all the compounds exhibited strong growth suppression due to apoptosis mediated by the activation of capsase-3. Ahmad et al. [107, 108] has demonstrated beneficial effects of garcinol in suppression of breast, prostate, and pancreatic cancer cell growth by induction of apoptosis which was mediated by caspase-3 followed by downregulation of the NFkB pathway.

4.2.4 Antibacterial and Antiulcer Activity

Iinuma et al. [81] evaluated garcinol, isogarcinol, and xanthochymol for their antibacterial activity against methicillin-resistant *Staphylococcus aureus* (MRSA) and results revealed high efficacy of all the compounds with minimum inhibitory concentration values ranging between 3.1 and 12.5 μg ml^{-1}. Various physical and psychological stresses cause gastric ulceration in human and experimental animals [109]. Recently oxygen-derived free radicals have been shown to play a role in experimental gastric damage induced by ischemia and reperfusion [110]. Yamaguchi et al. [96] have reported a significant free radical scavenging activity against hydroxyl radicals and it was vigorous than that of α-tocopherol. Therefore, garcinol is expected to be useful for preventing gastric ulcers. Yamguchi et al. [97] demonstrated that garcinol suppressed the gastric injury in rats induced by indomethacin and water immersion stress. These investigations suggest that garcinol may have potential as an antiulcer drug.

4.3 Biological Activity of Hydroxycitric Acid

Hydroxycitric acid (HCA) is the major organic acid found in the fruits of brindle berry and kokum. HCA exist in free form as well as in the lactone form, and HCA in free form is reported to possess potent biological activities [111]. HCA is an antiobesity drug and its activity is through regulation of serotonin and food intake suppression, decreased de novo lipogenesis, and enhanced fat oxidation [112]. Various in vivo studies have been carried out to understand these effects of HCA. HCA has been shown to be a strong inhibitor of ATP citrate lyase (EC 4.1.3.8) which catalyzes the cleavage of citrate to oxaloacetate and acetyl-Co-A, results in limitation of acetyl-Co-A required for fatty acid biosynthesis [113, 114]. As a consequence of this, the consumed carbon source is diverted to glycogen synthesis in liver, which results in signaling brain cells and increased production of serotonin and concomitant with a reduced appetite. Preuss et al. [115] reported that HCA generated a significant reduction in appetite, weight loss, and plasma leptin level, accompanying with an increase in the serum serotonin level and a favorable lipid profile in human clinical trials. Asghar et al. [116] conducted experiments in obese Zucker rats which were fed with HCA and recorded decrease in body weight combined with increased serotonin levels. Another possible consequence of HCA effect is the depletion of the acetyl-Co-A which is the precursor of fatty acid and cholesterol biosynthesis. Various in vitro and in vivo studies conducted in rodent models by Sullivan et al. [113, 114, 117, 118] established the inhibition of lopogenesis by HCA. Several experimental evidences suggest that HCA intake is also responsible for increased fat

oxidation. Ishihara et al. [119] carried out a study on acute and chronic effects of HCA on energy metabolism. Acute administrations of HCA (10 mg μl^{-1}) per mice significantly increased serum free fatty acid levels and levels of glycogen in the muscle; however, respiratory exchange was normal. In contrast, chronic administration of HCA (10 mg μl^{-1} twice a day) significantly lowered the respiratory quotient during resting and exercised conditions in mice. Lim et al. [120, 121] also reported that short-term administration of HCA led to fat oxidation in human volunteers.

4.4 Biological Activity of Anthocyanins

Chrysanthemin, cynidin-3-*O*-glucoside, and cynidin-3-*O*-sophoroside are the major anthocyanins isolated from fruits of mangosteen (Table 1) [4], whereas, kokum fruits were rich in anthocyanins namely cynidin-3-*O*-glucoside and cynidin-3-sambubioside [15]. The anthocyanins from kokum has a high prospective as a natural colorant and they are used in the production of confectionery, jellies, jams, health beverages, and deserts [59, 122]. Anthocyanins are having become more important in the food industry because of their bright and attractive shades and water solubility, which allows their incorporation into aqueous food systems [59, 123]. Various studies have also proved that anthocyanins are having possible health benefits as antioxidant, anti-inflammatory, anticancer, antidiabetic, cardio-protective, and neuroprotective agents [124–126]. In a study Min et al. [127] demonstrated neuroprotective effects cynidin-3-*O*-glucoside in a mouse model of permanent middle cerebral artery occlusion (pMCAO) even when delivered 3 h after the onset of ischemia, which is a clinically relevant time point in stroke. Cynidin-3-*O*-glucoside decreased cerebral superoxide levels, inhibited apoptosis-inducing (AIF) release from mitochondria, but did not influence the cytochrome-c related cell death pathway. Wang et al. [128] conducted a study to examine the role of cynidin-3-*O*-glucoside in the prevention of triple-negative breast cancer (TNBC). It was discovered that cynidin-3-*O*-glucoside preferentially promotes the apoptosis of TNBC cells, which co-express the estrogen receptor alpha 36 (ERα36) and the epidermal growth factor receptor (EGFR). Cynidin-3-*O*-glucoside binds to the legend-binding receptor of ERα36, inhibited EGFR/AKT signaling, and promotes EGFR degradation. In summary, all of the above, results indicate that cynidin-3-*O*-glucoside is an important anthocyanin possessing potent biological activities, and mangosteen and kokum fruits are rich in cynidin-3-*O*-glucoside; therefore, these fruits could be used as a potential source of cynidin-3-*O*-glucoside and other anthocyanins.

5 Conclusion

Latterly, Garcinia fruits especially mangosteen, brindle berry, and kokum are used in the preparation of nutraceuticals, dietary supplements, and other health foods because of their nutrient richness and chemical compounds with potential health

promoting properties. All the three fruits are rich in bioactive phytochemicals such as xanthone derivatives and benzophenone derivatives. Brindle berry and kokum are abundant with hydroxycitric acid. While, mangosteen and kokum fruits are rich in anthocyanin derivatives. Various in vitro and in vivo studies have shown that xanthone derivatives, benzophenone derivatives, and anthocyanins obtained from mangosteen, brindle berry, and kokum fruits possess antioxidant, anti-inflammatory, anticancer, antimicrobial, antiallergy, antiobesity, antiulcer, antiparasitic, and anti-helminthic properties. At the same time, hydroxycitric acid has been recognized as a potential antiobesity drug. In addition, various studies have suggested the safety of these natural compounds for human consumption and utilization [65, 112, 129–132]. Nevertheless, further preclinical and post-clinical studies are warranted to prove the efficacy and safety of these natural phytochemicals.

Acknowledgments This work was partially supported by DST-PURSE-PHASE-II program.

References

1. Lim TK (2012) Edible medicinal and non-medicinal plants. Fruits, vol 2. Springer, Heidelberg
2. Jung HA, Su BN, Keller WJ, Mehta RG, Kinghorn AD (2006) Antioxidant xanthones from the pericarp of *Garcinia mangostana* (Mangosteen). J Agric Food Chem 54:2077–2082. https://doi.org/10.1021/jf052649z
3. Fu C, Loo AEK, Chia FPP, Huang D (2007) Oligomeric proanthocyanidins from mangosteen pericarps. J Agric Food Chem 55:7689–7694. https://doi.org/10.1021/jf071166n
4. Farnsworth RN, Bunyapraphatsara N (1992) *Garcinia mangostana* Linn. In: Thai medicinal plants. Prachachon Co Ltd, Bangkok, pp 160–162
5. Ji X, Avula B, Khan IA (2007) Quantitative and qualitative determination of six xanthones in *Garcinia mangostana* L. by LC-PDA and LC-ESI-MS. J Pharm Biomed Anal 43:1270–1276. https://doi.org/10.1016/j.jpba.2006.10.018
6. Nakatani K, Atsumi M, Arakawa T, Oosawa K, Shimura S, Nakahata N, Ohizumi Y (2002) Inhibitions of histamine release and prostaglandin E2 synthesis by mangosteen, a Thai medicinal plant. Biol Pharm Bull 25:1137–1141. https://doi.org/10.1248/bpb.25.1137
7. Moongkarndi P, Kosem N, Luanratana O, Jongsomboonkusol S, Pongpan N (2004) Anti-proliferative activity of Thai medicinal plant extracts on human breast adenocarcinoma cell line. Fitoterapia 75:375–377. https://doi.org/10.1016/j.fitote.2004.01.010
8. Saralamp P, Chuakul W, Temsirirkkul R, Clayton T (1996) Medicinal plants in Thailand. Department of Pharmaceutical Botany, Faculty of Pharmacy, Bangkok, p 98
9. Yu L, Zhao M, Yang B, Zhao Q, Jiang Y (2007) Phenolics from hull of *Garcinia mangostana* fruit and their antioxidant activities. Food Chem 104:176–181. https://doi.org/10.1016/j.foodchem.2006.11.018
10. Sato A, Fujiwara H, Oku H, Ishiguro K, Ohizumi Y (2004) Alpha-mangostin induces Ca^{2+}-ATPase-dependent apoptosis via mitochondrial pathway in PC12 cells. J Pharmacol Sci 95:33–40. https://doi.org/10.1254/jphs.95.33
11. Jena BS, Jayaprakasha GK, Singh RP, Sakariah KK (2002) Chemistry and biochemistry of (−) hydroxycitric acid from *Garcinia*. J Agric Food Chem 50:10–22. https://doi.org/10.1021/jf010753k
12. Abraham Z, Malik SK, Rao GE, Narayanan SL, Biju S (2006) Collection and characterisation of Malabar tamarind [*Garcinia cambogia* (Gaertn.) Desr.] Genet Resour Crop Evol 53:401–406. https://doi.org/10.1007/s10722-004-0584-y

13. Ketsa S, Paull RE (2011) Mangosteen (*Garcinia mangostana* L.) In: Yahia EM (ed) Postharvest biology and technology of tropical and subtropical fruits, vol 4. Woodhead Publishing, Cambridge
14. Nazarudeen A (2010) Nutritional composition of some lesser-known fruits used by ethnic communities and local folks of Kerala. Indian J Tradit Knowl 9:398–402
15. Krishnamurthy N, Lewis YS, Ravindranath B (1982) Chemical constituents of kokam fruit rind. J Food Sci Technol 19:97–100
16. Nayak CA, Rastogi NK, Raghavarao KSMS (2010) Bioactive constituents present in *Garcinia indica* Choisy and its potential food applications: a review. Int J Food Prop 13:441–453. https://doi.org/10.1080/10942910802626754
17. Mishra A, Bapat MM, Tilak JC, Devasagayam TPA (2006) Antioxidant activity of *Garcinia indica* (kokam) and its syrup. Curr Sci 91:90–93
18. Peres V, Nagem TJ, De Oliveira FF (2000) Tetraoxygenated naturally occurring xanthones. Phytochemistry 55:683–710. https://doi.org/10.1016/S0031-9422(00)00303-4
19. Huang YL, Chen CC, Chen YJ, Huang RL, Shieh BJ (2001) Three xanthones and a benzophenone from *Garcinia mangostana*. J Nat Prod 64:903–906. https://doi.org/10.1021/np000583q
20. Pinto MMM, Sousa ME, Nascimento MSJ (2005) Xanthone derivatives: new insights in biological activities. Curr Med Chem 12:2517–2538. https://doi.org/10.2174/092986705774370691
21. Schmid W (1855) Ueber das mangostin. Liebigs Ann Chem 93:83–88
22. Dragendorff O (1930) Uber das harz von *Garcinia mangostana* L. Liebigs Ann 482:280–301
23. Chen LG, Yang LL, Wang CC (2008) Anti-inflammatory activity of mangostins from *Garcinia mangostana*. Food Chem Toxicol 46:688–693. https://doi.org/10.1016/j.fct.2007.09.096
24. Matsumoto K, Akao Y, Kobayashi E, Ohguchi K, Ito T, Tanaka T, Iinuma M, Nozawa Y (2003) Induction of apoptosis by xanthones from mangosteen in human leukemia cell lines. J Nat Prod 66:1124–1127. https://doi.org/10.1021/np020546u
25. Suksamrarn S, Komutiban O, Ratananukul P, Chimnoi N, Lartpornmatulee N, Suksamrarn A (2006) Cytotoxic prelylated xanthones from the young fruit of *Garcinia mangostana*. Chem Pharm Bull 54:301–305
26. Suksamrarn S, Suwannapoch N, Phakhodee W, Thanuhiranlert J, Ratananukul P, Chimnoi N, Suksamrarn A (2003) Antimycobacterial activity of prenylated xanthones from the fruits of *Garcinia mangostana*. Chem Pharm Bull (Tokyo) 51:857–859. https://doi.org/10.1248/cpb.51.857
27. Gopalakrishnan G, Banumathi B, Suresh G (1997) Evaluation of the antifungal activity of natural xanthones from *Garcinia mangostana* and their synthetic derivatives. J Nat Prod 60:519–524. https://doi.org/10.1021/np970165u
28. Yates P, Stout GH (1958) The structure of mangostin. J Am Chem Soc 80:1691–1700
29. Stout GH, Krahn MM, Yates P, Bhat HB (1968) The structure of mangostin. Chem Commun 4:211–212
30. Asai F, Tosa H, Tanaka T, Iinuma M (1995) A xanthone from pericarps of *Garcinia mangostana*. Phytochemistry 39:943–944. https://doi.org/10.1016/0031-9422(95)00042-6
31. Mahabusarakam W, Wiriyachitra P, Taylor WC (1987) Chemical constituents of *Garcinia mangostana*. J Nat Prod 50:474–478
32. Chin YW, Jung HA, Chai H, Keller WJ, Kinghorn AD (2008) Xanthones with quinone reductase-inducing activity from the fruits of *Garcinia mangostana* (Mangosteen). Phytochemistry 69:754–758. https://doi.org/10.1016/j.phytochem.2007.09.023
33. Chairungsrilerd N, Takeuchi K, Ohizumi Y, Nozoe S, Ohta T (1996) Mangostanol, a prenyl xanthone from *Garcinia mangostana*. Phytochemistry 43:1099–1102. https://doi.org/10.1016/S0031-9422(96)00410-4
34. Ho CK, Huang YL, Chen CC (2002) Garcinone E, a xanthone derivative, has potent cytotoxic effect against hepatocellular carcinoma cell lines. Planta Med 68:975–979. https://doi.org/10.1055/s-2002-35668

35. Suksamrarn S, Suwannapoch N, Ratananukul P, Aroonlerk N, Suksamrarn A (2002) Xanthones from the green fruit hulls of *Garcinia mangostana*. J Nat Prod 65:761–763. https://doi.org/10.1021/np010566g
36. Jefferson A, Quillinan AJ, Scheinmann F, Sim KY (1970) Isolation of γ-mangostin from *Garcinia mangostana* and preparation of the natural mangostins by selective demethylation. Aust J Chem 23:2539–2543
37. Jinsart W, Ternai B, Buddhasukh D, Polya GM (1992) Inhibition of wheat embryo calcium-dependant protein kinase and other kinases by mangostin and γ-mangostin. Phytochemistry 31:3711–3713
38. Gopalakrishnan G, Balaganesan B (2000) Two novel xanthones from *Garcinia mangostana*. Fitoterapia 71:607–609. https://doi.org/10.1016/S0367-326X(00)00199-4
39. Sen AK, Sarkar KK, Mazumder PC, Banerji N (1980) A xanthone from *Garcinia mangostana*. Phytochemistry 19:2223–2225
40. Govindachari TR, Kalyanaraman PS, Muthukumaraswamy N, Pai BR (1971) Xanthones of *Garcinia mangostana* Linn. Tetrahedron 27:3919–3926
41. Balasubramanian K, Rajagopalan K (1988) Novel xanthones from *Garcinia mangostana*, structures of BR-xanthone-A and BR-xanthone-B. Phytochemistry 27:1552–1554
42. Sen AK, Sarkar KK, Mazumder PC, Banerji N, Uusvuori R, Hase TA (1982) The structures of garcinones A, B and C: three new xanthones from *Garcinia mangostana*. Phytochemistry 21:1747–1750. https://doi.org/10.1016/S0031-9422(82)85052-8
43. Sen AK, Sarkar KK, Mazumder PC, Banerji N (1986) Garcinone-D, a new xanthone from *Garcinia mangostana* Linn. Indian J Chem 25B:1157–1158
44. Sakai S, Katsura M, Takayama H, Aimi N, Chokethaworn N, Suttajit M (1993) The structure of Garcinone E. Chem Pharm Bull 41:958–960
45. Ohno R, Moroishi N, Sugawa H, Maejima K, Saigusa M, Yamanaka M, Nagai M, Yoshimura M, Amakura Y, Nagai R (2015) Mangosteen pericarp extract inhibits the formation of pentosidine and ameliorates skin elasticity. J Clin Biochem Nutr 57:27–32
46. Du CT, Francis FJ (1977) A research note anthocyanins of mangosteen, *Garcinia mangostana*. J Food Sci 42:1667–1668
47. Zarena AS, Udaya Sankar K (2012) Isolation and identification of pelargonidin 3-glucoside in mangosteen pericarp. Food Chem 130:665–670. https://doi.org/10.1016/j.foodchem.2011.07.106
48. Lewis YS, Neelakantan S (1965) (−)-Hydroxycitric acid – the principal acid in the fruits of *Garcinia cambogia* Desr. Phytochemistry 4:619–625. https://doi.org/10.1016/S0031-9422(00)86224-X
49. Jayaprakasha GK, Sakariah KK (1998) Determination of organic acids in *Garcinia cambogia* (Desr.) by high- performance liquid chromatography. J Chromatogr A 806:337–339. https://doi.org/10.1016/S0021-9673(98)00054-5
50. Jayaprakasha GK, Sakariah KK (2000) Determination of (−) hydroxycitric acid in commercial samples of *Garcinia cambogia* extract by liquid chromatography with ultraviolet detection. J Liq Chromatogr Relat Technol 23:915–923. https://doi.org/10.1081/JLC-100101498
51. Mahapatra S, Mallik SB, Rao GV, Reddy GC, Row TNG (2007) *Garcinia* lactone. Acta Crystallogr E63:o3869. https://doi.org/10.1107/S160053680703838X
52. Masullo M, Bassarello C, Bifulco G, Piacente S (2010) Polyisoprenylated benzophenone derivatives from the fruits of *Garcinia cambogia* and their absolute configuration by quantum chemical circular dichroism calculations. Tetrahedron 66:139–145. https://doi.org/10.1016/j.tet.2009.11.034
53. Masullo M, Bassarello C, Suzuki H, Pizza C, Piacente S (2008) Polyisoprenylated benzophenones and an unusual polyisoprenylated tetracyclic xanthone from the fruits of *Garcinia cambogia*. J Agric Food Chem 56:5205–5210. https://doi.org/10.1021/jf800416j
54. Kolodziejczyk J, Masullo M, Olas B, Piacente S, Wachowicz B (2009) Effects of garcinol and guttiferone K isolated from *Garcinia cambogia* on oxidative/nitrative modifications in blood platelets and plasma. Platelets 20:487–492. https://doi.org/10.3109/09537100903165182

55. Masullo M, Menegazzi M, Di Micco S, Beffy P, Bifulco G, Dal Bosco M, Novelli M, Pizza C, Masiello P, Piacente S (2014) Direct interaction of garcinol and related polyisoprenylated benzophenones of *Garcinia cambogia* fruits with the transcription factor STAT-1 as a likely mechanism of their inhibitory effect on cytokine signaling pathways. J Nat Prod 77:543–549. https://doi.org/10.1021/np400804y
56. Jayaprakasha GK, Sakariah KK (2002) Determination of organic acids in leaves and rinds of *Garcinia indica* (Desr.) by LC. J Pharm Biomed Anal 28:379–384. https://doi.org/10.1016/S0731-7085(01)00623-9
57. Krishnamurthy N, Lewis YS, Ravindranath B (1981) On the structures of garcinol, isogarcinol and camboginol. Tetrahedron Lett 22:793–796
58. Chattopadhyay SK, Kumar S (2006) Identification and quantification of two biologically active polyisoprenylated benzophenones xanthochymol and isoxanthochymol in *Garcinia* species using liquid chromatography-tandem mass spectrometry. J Chromatogr B 844:67–83. https://doi.org/10.1016/j.jchromb.2006.07.045
59. Nayak CA, Srinivas P, Rastogi NK (2010) Characterization of anthocyanins from *Garcinia indica* Choisy. Food Chem 118:719–724. https://doi.org/10.1016/j.foodchem.2009.05.052
60. Jamila N, Choi JY, Hong JH, Nho EY, Khan N, Jo CH, Chun HS, Kim KS (2016) Identification and quantification of adulteration in *Garcinia cambogia* commercial products by chromatographic and spectrometric methods. Food Addit Contam Part A Chem 33:1751–1760. https://doi.org/10.1080/19440049.2016.1244733
61. Padhye S, Ahmad A, Oswal N, Sarkar FH (2009) Emerging role of garcinol, the antioxidant chalcone from *Garcinia indica* Choisy and its synthetic analogs. J Hematol Oncol 2(38):1–13. https://doi.org/10.1186/1756-8722-2-38
62. Chin YW, Kinghorn AD (2008) Structural characterization, biological effects, and synthetic studies on xanthones from mangosteen (*Garcinia mangostana*), a popular botanical dietary supplement. Mini Rev Org Chem 5:355–364. https://doi.org/10.2174/157019308786242223
63. Pedraza-Chaverri J, Cárdenas-Rodríguez N, Orozco-Ibarra M, Pérez-Rojas JM (2008) Medicinal properties of mangosteen (*Garcinia mangostana*). Food Chem Toxicol 46:3227–3239. https://doi.org/10.1016/j.fct.2008.07.024
64. Obolskiy D, Pischel I, Siriwatanametanon N, Heinrich M (2009) *Garcinia mangostana* L.: a phytochemical and pharmacological review. Phytother Res 23:1047–1065
65. Shan T, Ma Q, Guo K, Liu J, Li W, Wang F, Wu E (2011) Xanthones from mangosteen extracts as natural chemopreventive agents: potential anticancer drugs. Curr Mol Med 11:666–677. https://doi.org/10.2174/156652411797536679
66. Williams P, Ongsakul M, Proudfoot J, Croft K, Beilin L (1995) Mangostin inhibits the oxidative modification of human low density lipoprotein. Free Radic Res 23:175–184. https://doi.org/10.3109/10715769509064030
67. Mahabusarakam W, Proudfoot J, Taylor W, Croft K (2000) Inhibition of lipoprotein oxidation by prenylated xanthones derived from mangostin. Free Radic Res 33:643–659. https://doi.org/10.1080/10715760000301161
68. Sampath PD, Vijayaraghavan K (2007) Cardioprotective effect of α-mangostin, a xanthone derivative from mangosteen on tissue defense system against isoproterenol-induced myocardial infarction in rats. J Biochem Mol Toxicol 21:336–339
69. Pérez-Rojas JM, Cruz C, García-López P, Sánchez-González DJ, Martínez-Martínez CM, Ceballos G, Espinosa M, Meléndez-Zajgla J, Pedraza-Chaverri J (2009) Renoprotection by α -mangostin is related to the attenuation in renal oxidative/nitrosative stress induced by cisplatin nephrotoxicity. Free Radic Res 43:1122–1132. https://doi.org/10.1080/10715760903214447
70. Buelna-Chontal M, Correa F, Hernández-Reséndiz S, Zazueta C, Pedraza-Chaverri J (2011) Protective effect of α-mangostin on cardiac reperfusion damage by attenuation of oxidative stress. J Med Food 14:1370–1374. https://doi.org/10.1089/jmf.2010.0238
71. Shankaranarayan D, Gopalakrishnan C, Kameswaran L (1979) Pharmacological profile of mangostin and its derivatives. Arch Int Pharmacodyn Ther 239:257–269

72. Deschamps JD, Gautschi JT, Whitman S, Johnson TA, Gassner NC, Crews P, Holman TR (2007) Discovery of platelet-type 12-human lipoxygenase selective inhibitors by high-throughput screening of structurally diverse libraries. Bioorg Med Chem 15:6900–6908. https://doi.org/10.1016/j.bmc.2007.08.015
73. Chae HS, Oh SR, Lee HK, Joo SH, Chin YW (2012) Mangosteen xanthones, α- and γ-mangostins, inhibit allergic mediators in bone marrow-derived mast cell. Food Chem 134:397–400. https://doi.org/10.1016/j.foodchem.2012.02.075
74. Akao Y, Nakagawa Y, Iinuma M, Nozawa Y (2008) Anti-cancer effects of xanthones from pericarps of mangosteen. Int J Mol Sci 9:355–370. https://doi.org/10.3390/ijms9030355
75. Matsumoto K, Akao Y, Ohguchi K, Ito T, Tanaka T, Iinuma M, Nozawa Y (2005) Xanthones induce cell-cycle arrest and apoptosis in human colon cancer DLD-1 cells. Bioorg Med Chem 13:6064–6069. https://doi.org/10.1016/j.bmc.2005.06.065
76. Kurose H, Shibata M-A, Iinuma M, Otsuki Y (2012) Alterations in cell cycle and induction of apoptotic cell death in breast cancer cells treated with α -mangostin extracted from mangosteen pericarp. J Biomed Biotechnol 2012:1–9. https://doi.org/10.1155/2012/672428
77. Hung S-H, Shen K-H, C-H W, Liu C-L, Shih Y-W (2009) α-Mangostin suppresses PC-3 human prostate carcinoma cell metastasis by inhibiting matrix metalloproteinase-2/9 and urokinase-plasminogen expression through the JNK signaling pathway. J Agric Food Chem 57:1291–1298
78. Wang Y, Xia Z, JR X, Wang YX, Hou LN, Qiu Y, Chen HZ (2012) α-Mangostin, a polyphenolic xanthone derivative from mangosteen, attenuates β-amyloid oligomers-induced neurotoxicity by inhibiting amyloid aggregation. Neuropharmacology 62:871–881. https://doi.org/10.1016/j.neuropharm.2011.09.016
79. Aisha AFA, Abu-Salah KM, Ismail Z, Majid AMSA (2012) In vitro and in vivo anti-colon cancer effects of *Garcinia mangostana* xanthones extract. BMC Complement Altern Med 12:104–113. https://doi.org/10.1186/1472-6882-12-104
80. Mahabusarakam W, Wiriyachitra P, Phongpaichit S (1986) Antimicrobial activities of chemical constituents from *Garcinia mangostana* Linn. J Sci Soc Thail 12:239–242
81. Iinuma M, Tosa H, Tanaka T, Asai F, Kobayashi Y, Shimano R, Miyauchi KI (1996) Antibacterial activity of xanthones from guttiferaeous plants against methicillin-resistant *Staphyloococcus aureus*. J Pharm Pharmacol 48:861–865. https://doi.org/10.1111/j.2042-7158.1996.tb03988.x
82. Chomnawang MT, Surassmo S, Wongsariya K, Bunyapraphatsara N (2009) Antibacterial activity of Thai medicinal plants against methicillin-resistant *Staphylococcus aureus*. Fitoterapia 80:102–104
83. Koh JJ, Qiu S, Zou H, Lakshminarayanan R, Li J, Zhou X, Tang C, Saraswathi P, Verma C, Tan DTH, Tan AL, Liu S, Beuerman RW (2013) Rapid bactericidal action of alpha-mangostin against MRSA as an outcome of membrane targeting. Biochim Biophys Acta Biomembr 1828:834–844. https://doi.org/10.1016/j.bbamem.2012.09.004
84. Torrungruang K, Vichienroj P, Chutimaworapan S (2007) Antibacterial activity of mangosteen pericarp extract against cariogenic *Streptococcus mutans*. CU. Dent J 30:1–10
85. Sundaram BM, Gopalakrishnan C, Subramanian S, Shankaranarayanan D, Kameswaran L (1983) Antimicrobial activities of *Garcinia mangostana*. Planta Med 48:59–60. https://doi.org/10.1055/s-2007-969882
86. Chen SX, Wan M, Loh BN (1996) Active constituents against HIV-1 protease from *Garcinia mangostana*. Planta Med 62:381–382. https://doi.org/10.1055/s-2006-957916
87. Kaomongkolgit R, Jamdee K, Chaisomboon N (2009) Antifungal activity of alpha-mangostin against *Candida albicans*. J Oral Sci 51:401–406. https://doi.org/10.2334/josnusd.51.401
88. Ee GCL, Daud S, Taufiq-Yap YH, Ismail NH, Rahmani M (2006) Xanthones from *Garcinia mangostana* (Guttiferae). Nat Prod Res 20:1067–1073. https://doi.org/10.1080/14786410500463114
89. Bullangpoti V, Visetson S, Milne J, Milne M, Sudthongkong C, Pronbanlualap S (2007) Effects of alpha-mangostin from mangosteen pericarp extract and imidacloprid on *Nilaparvata*

lugens (Stal.) and non-target organisms: toxicity and detoxification mechanism. Commun Agric Appl Biol Sci 72:431–441
90. Larson RT, Lorch JM, Pridgeon JW, Becnel JJ, Clark GG, Lan Q (2010) The biological activity of α-Mangostin, a larvicidal botanic mosquito sterol carrier protein-2 inhibitor. J Med Entomol 47:249–257
91. Kim M-S, Lan Q (2011) Larvicidal activity of α-mangostin in the Colorado potato beetle, *Leptinotarsa decemlineata*. J Pestic Sci 36:370–375. https://doi.org/10.1584/jpestics.G11-09
92. Bullangpoti V, Visetson S, Milne J, Pornbanlualap S (2004) Effects of mangosteen's peels and rambutan's seeds on toxicity, esterase and glutathione-*S*-transferase in rice weevil (*Sitophilus oryzae* L.) Kasetsart J (Nat Sci) 38:84–89
93. Bullangpoti V, Visetson S, Milne M, Milne J, Pornbanlualap S, Sudthongkongs C, Tayapat S (2006) The novel botanical insecticide for the control brown planthopper (*Nilaparvata lugens* Stal.) Commun Agric Appl Biol Sci 71:475–481
94. Keiser J, Vargas M, Winter R (2012) Anthelminthic properties of mangostin and mangostin diacetate. Parasitol Int 61:369–371. https://doi.org/10.1016/j.parint.2012.01.004
95. Wu S-B, Long C, Kennelly EJ (2014) Structural diversity and bioactivities of natural benzophenones. Nat Prod Rep 31:1158–1174. https://doi.org/10.1039/C4NP00027G
96. Yamaguchi F, Ariga T, Yoshimura Y, Nakazawa H (2000) Antioxidative and anti-glycation activity of garcinol from *Garcinia indica* fruit rind. J Agric Food Chem 48:180–185
97. Yamaguchi F, Saito M, Ariga T, Yoshimura Y (2000) Free radical scavenging activity and antiulcer activity of garcinol from *Garcinia indica* fruit rind. J Agric Food Chem 48:2320–2325
98. Hong J, Sang S, Park H-J, Kwon SJ, Suh N, Huang M-T, Ho C-T, Yang CS (2006) Modulation of arachidonic acid metabolism and nitric oxide synthesis by garcinol and its derivatives. Carcinogenesis 27:278–286. https://doi.org/10.1093/carcin/bgi208
99. Sang S, Pan M, Cheng X, Bai N, Stark RE, Rosen RT, Lin-Shiau SY, Lin JK, Ho CT (2001) Chemical studies on antioxidant mechanism of garcinol: analysis of radical reaction products of garcinol with their antitumor activities. Tetrahedron 57:9931–9938
100. Sang S, Liao CH, Pan MH, Rosen RT, Lin-Shiau SY, Lin JK, Ho CT (2002) Chemical studies on antioxidant mechanism of garcinol: analysis of radical reaction products of garcinol with peroxyl radicals and their antitumor activities. Tetrahedron 58:10095–10102. https://doi.org/10.1016/S0040-4020(02)01411-4
101. Hung W, Liu C, Lai C, Ho C, Pan M (2015) Inhibitory effect of garcinol against 12-*O*-tetradecanoylphorbol 13-acetate-induced skin inflammation and tumorigenesis in mice. J Funct Foods 18:65–73
102. Koeberle A, Northoff H, Werz O (2009) Identification of 5-lipoxygenase and microsomal prostaglandin E2 synthase-1 as functional targets of the anti-inflammatory and anti-carcinogenic garcinol. Biochem Pharmacol 77:1513–1521
103. Tanaka T, Kohno H, Shimada R, Kagami S, Yamaguchi F, Kataoka S, Ariga T, Murakami A, Koshimizu K, Ohigashi H (2000) Prevention of colonic aberrant crypt foci by dietary feeding of garcinol in male F344 rats. Carcinogenesis 21:1183–1189. https://doi.org/10.1093/carcin/21.6.1183
104. Liao C, Ho C, Lin J (2005) Effects of garcinol on free radical generation and NO production in embryonic rat cortical neurons and astrocytes. Biochem Biophys Res Commun 329:1306–1314. https://doi.org/10.1016/j.bbrc.2005.02.110
105. Hong J, Joo S, Sang S, Ju J, Zhou J (2007) Effects of garcinol and its derivatives on intestinal cell growth : inhibitory effects and autoxidation-dependent growth-stimulatory effects. Free Radic Biol Med 42:1211–1221. https://doi.org/10.1016/j.freeradbiomed.2007.01.016
106. Pan M, Chang W, Ho C, Lin J (2001) Induction of apoptosis by garcinol and curcumin through cytochrome *c* release and activation of caspases in human leukemia HL-60 cells. J Agric Food Chem 49:1464–1474
107. Ahmad A, Wang Z, Ali R, Maitah MY, Kong D, Banerjee S, Padhye S, Sarkar FH (2010) Apoptosis-inducing effect of garcinol is mediated by NF-κB signaling in breast cancer cells. J Cell Biochem 109:1134–1141. https://doi.org/10.1002/jcb.22492

108. Ahmad A, Wang Z, Wojewoda C, Ali R, Kong D, Maitah MY, Banerjee S, Bao B, Padhye S, Sarkar FH (2011) Garcinol-induced apoptosis in prostate and pancreatic cancer cells is mediated by NF- kB signaling. Front Biosci (Elite Ed) 3:1483–1492
109. Miller TA (1987) Mechanisms of stress-related mucosomal damage. Am J Med 83:8–14
110. Perry MA, Wadhwa S, Parks DA, Pickard WES, Granger DN (1986) Role of oxygen radicals in ischemia-induced lesions in the cat stomach. Gastroenterology 90:362–367
111. De Haar JL, Wielinga PY, Scheurink AJW, Nieuwenhuizen AG (2005) Comparison of the effects of three different (−)-hydroxycitric acid preparations on food intake in rats. Nutr Metab 2:1–9
112. Chuah LO, Ho WY, Beh BK, Yeap SK (2013) Updates on antiobesity effect of *Garcinia* origin (−)-HCA. Evid Based Complement Alternat Med 2013:1–17. https://doi.org/10.1155/2013/751658
113. Sullivan AC, Triscari J, Spiegel HE (1977) Metabolic regulation as a control for lipid disorders. I. Influence of, (−)-hydroxycitrate on experimentally induced obesity in the rodent. Am J Clin Nutr 30:767–776
114. Sullivan AC, Triscari J, Spiegel HE (1977) Metabolic regulation as a control for lipid disorders. II. Influence of (−)-hydroxycitrate on genetically and experimentally induced hypertriglyceridemia in the rat. Am J Clin Nutr 30:777–784
115. Preuss HG, Bagchi D, Bagchi M, Rao CVS, Dey DK, Satyanarayana S (2004) Effects of a natural extract of (−)-hydroxycitric acid (HCA-SX) and a combination of HCA-SX plus niacin-bound chromium and *Gymnema sylvestre* extract on weight loss. Diabetes Obes Metab 6:171–180
116. Asghar M, Zeyssig R, Monjok E, Kouamou G, Ohia SE, Lokhandwala MF, Bagchi D (2006) Hydroxycitric acid (HCA-SX) decreases oxidative stress and insulin resistance and increases brain serotonin levels in obese Zucker rats. Exp Biol Meet 20:A655.4
117. Sullivan AC, Triscari J, Hamilton JG (1974) Effect of (−)-hydroxycitrate upon the accumulation of lipid in the rat: I. Lipogenesis. Lipids 9:121–128
118. Sullivan AC, Triscari J, Hamilton JG, Miller ON (1974) Effect of (−)-hydroxycitrate upon the accumulation of lipid in the rat: II. Appetite. Lipids 9:129–134
119. Ishihara K, Oyaizu S, Onuki K, Lim K, Fushiki T (2000) Chronic (−)-hydroxycitrate administration spares carbohydrate utilization and promotes lipid oxidation during exercise in mice. J Nutr 130:2990–2995
120. Lim K, Ryu S, Ohishi Y, Watanabe I, Tomi H, Suh H, Lee W, Kwon T (2002) Short-term (−)-hydroxycitrate ingestion increases fat oxidation during exercise in athletes. J Nutr Sci Vitaminol 48:128–133
121. Lim K, Ryu S, Nho H, Choi S, Kwon T, Suh H, So J, Tomita K, Okuhara Y, Shigematsu N (2003) (−)-Hydroxycitric acid ingestion increases fat utilization during exercise in untrained women. J Nutr Sci Vitaminol 49:163–167
122. Bhat DJ, Kamat N, Shirodkar A (2005) Compendium and proceedings of 2nd National seminar on Kokum (*Garcinia indica* Choicy), March 4–5, 2005 held at Goa University
123. Francis FJ, Markakis PC (1989) Food colorants : anthocyanins. Crit Rev Food Sci Nutr 28:273–314
124. Scazzocchio B, Varì R, Filesi C, D'Archivio M, Santangelo C, Giovannini C, Iacovelli A, Silecchia G, Volti GL, Galvano F, Masella R (2011) Cyanidin-3-*O*-β-glucoside and protocatechuic acid exert insulin-like effects by upregulating PPARγ activity in human omental adipocytes. Diabetes 60:2234–2244. https://doi.org/10.2337/db10-1461
125. Pojer E, Mattivi F, Johnson D, Stockley CS (2013) The case for anthocyanin consumption to promote human health: a review. Compr Rev Food Sci Food Saf 12:483–508. https://doi.org/10.1111/1541-4337.12024
126. Ferrari D, Cimino F, Fratantonio D, Molonia MS, Bashllari R, Busà R, Saija A, Speciale A (2017) Cyanidin-3-*O*-glucoside modulates the in vitro inflammatory crosstalk between intestinal epithelial and endothelial cells. Mediators Inflamm. 2017, 8 pages doi: https://doi.org/10.1155/2017/3454023

127. Min J, Yu SW, Baek SH, Nair KM, Bae ON, Bhatt A, Kassab M, Nair MG, Majid A (2011) Neuroprotective effect of cyanidin-3-*O*-glucoside anthocyanin in mice with focal cerebral ischemia. Neurosci Lett 500:157–161. https://doi.org/10.1016/j.neulet.2011.05.048
128. Wang L, Li H, Yang S, Ma W, Liu M, Guo S, Zhan J, Zhang H, Tsang SY, Zhang Z, Wang Z, Li X, Guo Y-D, Li X (2016) Cyanidin-3-*O*-glucoside directly binds to ERα36 and inhibits EGFR-positive triple-negative breast cancer. Oncotarget 7:68864–68882. https://doi.org/10.18632/oncotarget.12025
129. Gutierrez-Orozco F, Failla ML (2013) Biological activities and bioavailability of mangosteen xanthones: a critical review of current evidences. Forum Nutr 5:3163–3183
130. Marquez F, Babio N, Bullo M, Salas-Salvodo J (2012) Evaluation of the safety and efficacy of hydroxycitric acid or *Garcinia cambogia* extracts in humans. Crit Rev Food Sci 52:585–594
131. Saadat N, Gupta SV (2012) Potential review of garcinol as an anticancer agent. J Oncol 2012:1–8. https://doi.org/10.1155/2012/647206
132. Yousuf B, Gul K, Wani AA, Singh P (2016) Health benefits of anthocyanins and their encapsulation for potential used in food system: a review. Crit Rev Food Sci 56:2223–2230