

A review on anthraquinones isolated from *Cassia* species and their applications

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Cassia Linn. (Family — Caesalpiniaceae) is a large tropical genus with about 600 species of herbs, shrubs and trees. Most of the plants of the genus are wellknown in Indian system of medicine for their cathartic, purgative and antibiotic properties. Many compounds of structural significance and medicinal importance have been reported from different species of this genus. Species of *Cassia* are rich source of anthraquinones which are wellknown as natural dyes, and are gaining importance in recent years due to environmental pollution caused by synthetic dyes. This paper attempts to give an overview of literature on the isolated and characterized anthraquinones from various *Cassia* species and their reported applications. Besides dye yielding properties they are used in cosmetics and pharmaceuticals. Thus plants of *Cassia* species can serve as commercial source of naturally occurring anthraquinones.

Keywords: Anthraquinones, Biologically active metabolites, *Cassia*, Caesalpiniaceae, Pharmacological applications.

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Introduction

Various natural products have been isolated from number of plant species. These isolated natural products have remarkable variety of compounds having unusual structures, many of which have found uses in the cosmetic dye and pharmaceutical industries. In addition these compounds are plant growth regulators, fungicides, insecticides, pest control agents and repellents of herbivores. With increase in awareness about environment and sustainable development natural products found to be new area of research due to its biodegradable nature and production from renewable resources. Review of compounds isolated from plant is important as these compounds have served as lead compounds for additional research, or that continue to be of interest to researchers in multiple areas¹. Anthraquinones are one of such compounds which occur naturally in some plants, fungi, lichens, and insects, where they serve as a basic skeleton for their pigments. Natural anthraquinones are study of interest due to its wide range of applications.

Anthraquinones are group of functionally diverse aromatic chemicals, structurally related to anthracene, with parent structure 9,10-dioxoanthracene. It has the appearance of yellow or light gray to gray-green solid crystalline powder. Its other names are 9,10-anthracenedione, anthradione, 9,10-anthrachinon, anthracene-9,10-quinone and 9,10-dihydro-9,10-dioxoanthracene. The vegetables used in human diet showed a large batch-to-batch variability, from 0.04 to 3.6, 5.9 and 36 mg total anthraquinone per kg fresh weight in peas, cabbage, lettuce and beans, respectively with physcion predominated in all vegetables². Anthraquinone compounds are used as laxatives mainly from their glycosidic derivatives and also used in the treatment of fungal skin diseases³. Anthraquinones and its derivatives are frequently found in slimming agents and have been valued for their cathartic and presumed detoxifying action however, may cause nausea, vomiting, abdominal cramps and diarrhoea with both therapeutic dose and over dose³. Anthraquinone derivatives show antioxidant property in following order: BHA (96%), anthrone (95%), alizarin (93%), aloe-emodin (78%), rhein (71%), emodin (36%) and anthraquinone (8%)⁴.

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Both natural and synthetic anthraquinones have wide-spread applications throughout industry and medicine, thereby indirectly and directly exposing the human population⁵. Plant extracts containing anthraquinones are being increasingly used for cosmetics, food, dye and pharmaceuticals due to their wide therapeutic and pharmacological properties⁶. Some of the reported applications of anthraquinones and their chemical structures are summarized in Table 1^(Refs 6-28) and Figs 1-37.

Anthraquinone from various *Cassia* species

Cassia Linn. a major genus of Caesalpiniaceae family, contains four sections comprising about 600 species; some of which widely distributed throughout the world especially in tropical countries and is abundantly available in India. The genus *Cassia* is widely distributed in tropical and subtropical regions and is used in traditional folk medicine, particularly for the treatment of periodic fever and malaria. The species are good source of mucilage, flavonoids, anthraquinones and polysaccharides²⁹. Several of them yield timber, tannins and dyes, fodder, vegetables, edible fruits and seeds used as substitute for coffee. About 45 species are found in India of which few have been introduced for ornament³⁰. There are 28 tropical species in *Cassia* Linn. sect. *Fistula* and six of these, viz. *C. grandis* Linn., *C. fistula* Linn., *C. nodosa* Hamilt, *C. renigera* Wall., *C. javanica* Linn. and *C. marginata* Roxb. are found in Indian flora. Phytochemical investigation reveals that all six species contain kaempferol and a mixture of anthraquinones which include chrysophanol (Fig. 1), rhein (Fig. 2) and physcion (Fig. 3)³¹. Formation of hydroxyanthraquinone has been demonstrated in cell cultures of *C. angustifolia* Vahl, *C. senna* Linn. and *C. tora* and they are important source of anthraquinone laxatives. The hydroxyl anthraquinones are synthesized in these plants via the acetate malonate pathway³². A large number of anthraquinones are identified from various parts of cassia species are reported and described³⁰. In the following text, anthraquinones from different cassia species are reviewed along with pharmacological properties of cassia species due to presence of anthraquinones.

Cassia absus Linn.

It is an erect, annual plant 30-60 cm high, distributed throughout India. All plant parts of the species are used in folk medicine. The leaves are

bitter, acrid and astringent. The seeds are used in the treatment of ophthalmia and skin infections and as cathartic. The seeds are also used in syphilitic ulcers and leucoderma³³. The leaves are used in treatment of tumors and asthma, while roots are used for treatment of constipation. The reported medicinal uses of roots are consistent with the presence of chrysophanol (Fig. 1) and aloe-emodin (Fig. 4) (Table 2)³⁴.

Cassia acutifolia Delile

It is native to India and cultivated mainly in South India and Pakistan. The parts of this plant used medicinally are the leaves and pods. The leaves have purging quality, but afterwards have binding effect. Both the leaves and pods are used in many over-the-counter pharmaceutical preparations. It is a purgative having active ingredients anthraquinone derivatives and their glucosides, acting on the lower bowel, and is especially useful in alleviating constipation. Various anthraquinones reported from different plant parts (Table 2) supports its medicinal properties^{35,36}.

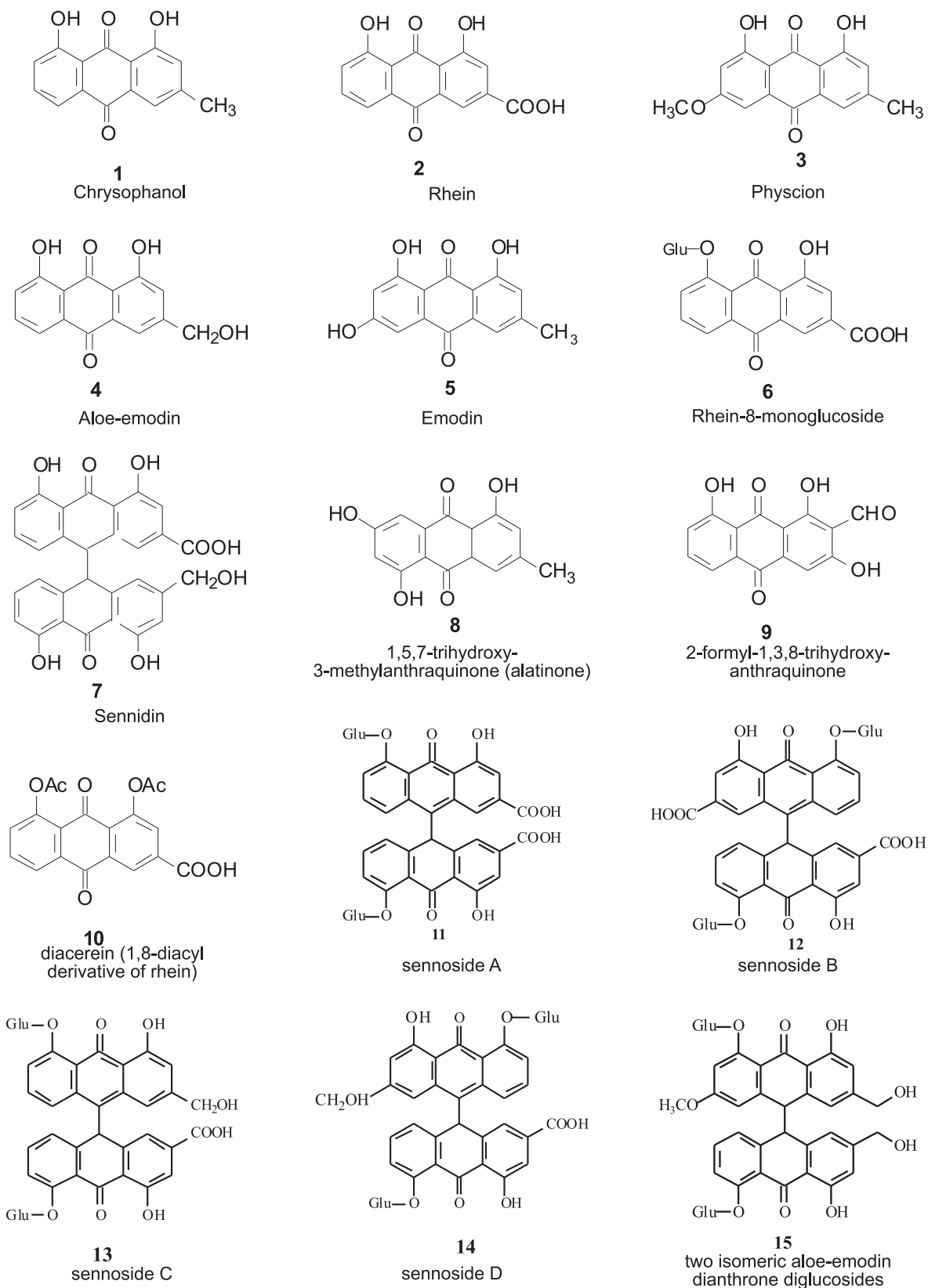
Nazif *et al* (2000) had studied the effect of salt stress on suspension cultures of *C. acutifolia* established by transferring callus tissues derived from root, hypocotyl and cotyledon explants onto liquid MS-medium supplemented with 1.0 mg/l 2,4-D and 0.1 mg/l kinetin and containing increasing levels of NaCl and reported that stress induced by NaCl raised anthraquinone content and reduced growth of cultures. The levels of anthraquinones and their glycosides as sennosides showed distinct changes in cells and media as well as in the different cultures initiated from various explants. Furthermore, the salt stress tended to affect more drastically the productivity of anthraquinones in hypocotyl and cotyledon cell cultures than in root cultures³⁵.

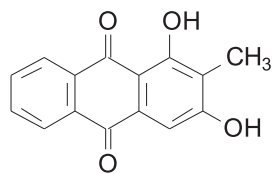
Cassia alata Linn.

It is a native of tropical America but now widely distributed in tropics mainly in western and eastern Africa and India. Its seeds are reported to be alternative of legumes due to high protein and carbohydrates³⁷. It is a pantropical, ornamental shrub, which commonly known as Ringworm Senna as the leaf extract of the plant have been reported to possess medicinal properties against ringworm, scabies, ulcers and other skin diseases such as pruritis, eczema and itching³⁸. Aqueous extract of the plant could be used effectively as antidermatophytic agents as it inhibits the ringworm infection. The leaves in the form of

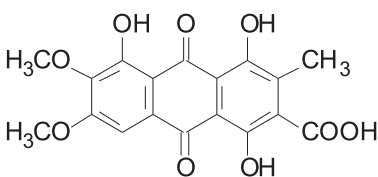
Table 1 — Summary of reported applications of anthraquinones

Anthraquinone	Reported Uses	Ref. No.
Barbaloin and emodin	Antiviral activity, anthraquinone-loaded liposomes may suppose an alternative for antimicrobial, pharmaceutical or cosmetic applications	6
1,8-dihydroxyanthraquinone and derivatives of 9,10-anthracenedione	Inhibit respiratory sulfate reduction by pure cultures of sulfate-reducing bacteria, as well as by crude enrichment cultures	7
Emodin	Innovative and safe chemotherapeutic strategy can be developed that uses natural anthraquinone derivatives as reactive oxygen species generators to increase the susceptibility of tumour cells to cytotoxic therapeutic agents	8
Hydroxylated anthraquinones	Long-term ingestion of certain anthraquinones, may affect the toxicity of other components present in the diet through the hepatic induction or inhibition of P450 1A2	9
Various substituted 9,10-anthraquinones	Inhibitory activities on photosystem II electron transport	10
Anthraquinone-based intercalating drugs, including the anti-cancer agent mitoxantrone	Enhancements to enzymatic cutting of DNA were observed cluster around AT-rich regions.	11
Alizarin, purpurin, lac color, and cochineal extract	Significant antigenotoxic activities against the eight carcinogens	12
Two series of 1,4-bis(2-amino-ethylamino) anthraquinone-amino acid conjugates (BACs), ametantrone (AT)-amino acid conjugates (AACs) and mitoxantrone (MX)-amino acid conjugates (MACs)	MAC 16 may provide a lead for the development of novel generations of anthraquinone-type antitumor agents	13
Hydrophobic anthraquinone (1C3) moiety	Pt-1C3 complex may represent an effective system for the delivery of the platinum moiety to nuclear DNA	14
1,4-bihydroxyanthraquinone (quinizarin), 1,5-dihydroxyanthraquinone (anthrarufin), 1,8-dihydroxyanthraquinone (danthron), and 5-hydroxy-1,4-naphthoquinone (juglone)	Strongly suppressed DNA-binding activity of the aryl hydrocarbon receptor (AhR) induced by 0.1 M 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD), with their IC ₅₀ values around 1 μM. The findings of this study may be useful for the design of the novel antagonists of the aryl hydrocarbon receptor (AhR)	15
1-(3-alkynoxy)-9,10-anthraquinones	Moderate yields (35-45%) of 3-alkynals by photolysis which has potential to play an important role in synthesis by selective reaction of their isolated functional groups	16
Natural anthraquinones	Inactivate enveloped viruses	17
Anthraquinones and anthraquinone derivatives with the hydroxyl and alkyl substitution pattern of emodin	Antiviral and virucidal activities against viruses representing several taxonomic groups	18
Polyphenolic and/or polysulfonate substituted anthraquinones	Anti-HIV-1 activity	19
Hypericin	Antiviral activity against vesicular stomatitis virus, herpes simplex virus types 1 and 2, parainfluenza virus, and vaccinia virus, HIV-1, retroviruses at conc. of less than 1 μg/ml	18,19
Quinalizarin, emodin, rhein, hypericin, protohypericin, alizarin, emodin bianthrone and emodin anthrone	Antiviral activity against human cytomegalovirus (HCMV)	20
Acid blues, acid black, alizarin violet R and reactive blue	These compounds could be a prototype for synthesizing even more effective HCMV-inhibitory anthraquinone derivatives	21
Chrysophanic acid	Inhibit the replication of poliovirus types 2 and 3	22
Anthraquinone dyes	1-hydroxyl and 4-hydroxyl groups in the anthraquinone structure are key factors in hypersensitivity induction by anthraquinone-related compounds	23
9,10-Anthraquinone-2-sulfonic acid Na-salt (AQS2), 9,10-anthraquinone-1,5-disulfonic Na-salt (AQDS1,5) and 1,4-dihydroxy-9,10-anthraquinone (DHAQ1,4)	Accelerating effect of anthraquinone as a redox mediator in the biodecolorization of dispersed organic dyestuffs	24
Immobilized anthraquinone	Decolorization of azo dyes using the salt-tolerant bacteria	25
Three anthraquinone dyes with carboxylic acid as anchoring group	Broad and intense absorption spectra in the visible region (up to 800 nm)	26
Substituted 1,4-anthraquinones	Quench bacteriorhodopsin tryptophan fluorescence	27
9,10-anthraquinone and substituent	Anthraquinone anions that are responsible for the O ₂ ⁻ generation in polar solvent	28

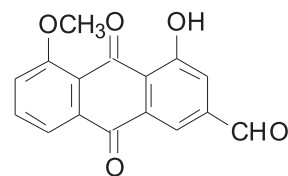
Figs 1-15 — Chemical structures of some anthraquinones present in *Cassia* species



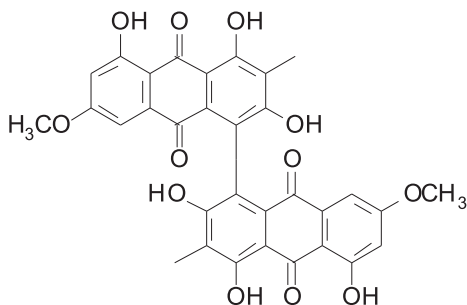
16
1,3-dihydroxy-2-methyl
anthraquinone (Rubiadin)



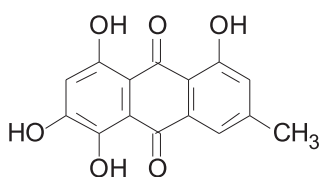
17
fistulic acid



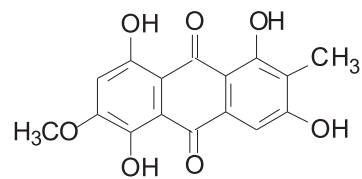
18
3-formyl-1-hydroxy-
8-methoxyanthraquinone



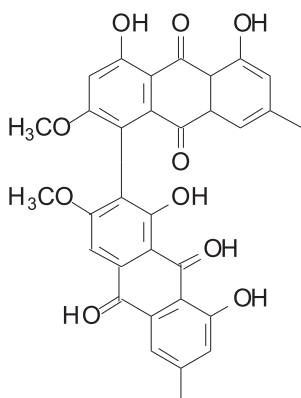
19
4,4'-bis(1,3,8-trihydroxy-
6-methoxy-2-methyl) anthraquinone



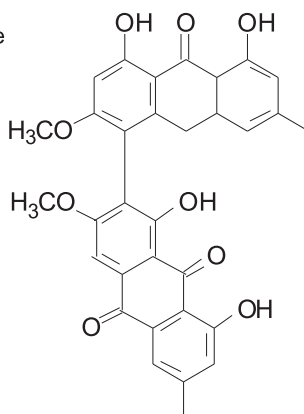
20
5-hydroxy emodin



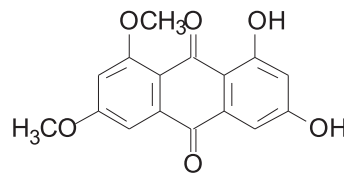
21
1,3,5,8-tetrahydroxy-6-methoxy-
2-methyl-anthraquinone



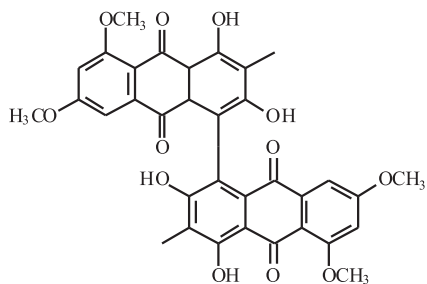
22
floribundone 1



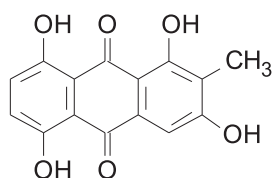
23
floribundone 2



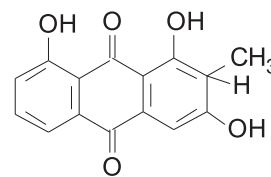
24
1,3-dihydroxy-6,
8-dimethoxyanthraquinone



25
4,4'-bis(1,3-dihydroxy-6,
8-dimethoxy-2-methylanthraquinone)

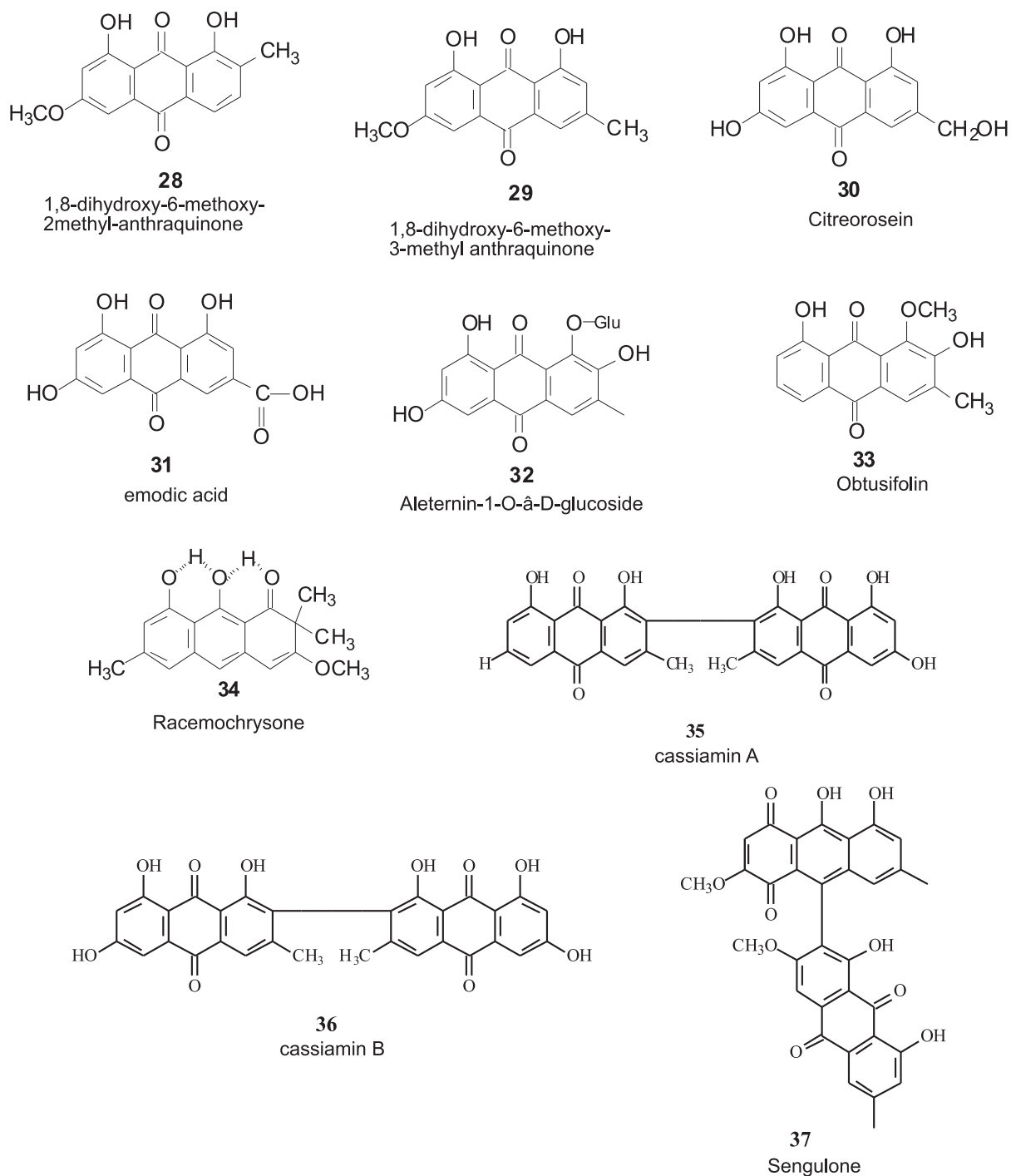


26
1,3,5,8-tetra-hydroxy-
2-methyl anthraquinone



27
1,2-dihydro-1,3,8-trihydroxy-
2-methyl anthraquinone

Figs 16-27 — Chemical structures of some anthraquinines present in *Cassia* species

Figs 28-37 — Chemical structures of some anthraquinones present in *Cassia* species

paste with or without lime juice are regarded as an excellent topical remedy for ringworm in Indian native medicinal³⁹. Decoction of wood is useful in cases of constipation⁴⁰. Crude ethanol and water extract of barks shown *in vitro* antimicrobial activity against fungi, yeast, and bacteria, while water extract

exhibited higher antibacterial activity than the ethanol extract from leaves⁴¹. The methanol extracts of leaves, flowers, stem and root barks of showed a broad spectrum of antibacterial activity while the dichloromethane fraction of the flower extract being the most effective⁴². Various authors have reported

antifungal properties of extracts of its leaves and isolated anthraquinones (Table 2) as main constituents for antifungal effect^{30,43-46}. Damodaran and Venkataraman (1994) reported the therapeutic efficacy of *C. alata* leaf extract against *Pityriasis versicolor* for the first time involving humans. The study indicated that the leaf extract can be reliably used as an herbal medicine to treat *P. versicolor* without any side-effects on humans⁴⁷.

Leaf extract of it reduce the blood sugar value in streptozotocin-induced hyperglycemic animals while the extract has no effect on glucose levels in normoglycemic animals⁴⁸ and also showed the analgesic activity⁴⁹. The leaf extract has been found to produce fall in blood sugar level in dogs and rats⁴⁰ which may be related to anthraquinones.

The leaves of this plant are reported to contain anthraquinone compounds both free aglycones and glycosides which have laxative effect⁵⁰. Panichayupakaranant and Intaraksa (2003) demonstrated poor quality of *C. alata* leaves due to the content of hydroxyanthracene derivatives being lower than the standard value (that is not less than 1.0% w/w of hydroxyanthracene derivatives, calculated as rhein-8-glucoside on a dried basis) has been a major problem in the production of the herbal medicines from *C. alata*. They have studied the effect of harvesting and post-harvesting factors on the quality of *C. alata* raw material and carried out analysis on the content of hydroxyanthracene derivatives of the leaves, flowers and pods of it, which had been collected at different harvesting times and different positions⁵¹. They found that when the leaves were harvested in March, June or September, the hydroxyanthracene derivatives were accumulated more in the the young and mature leaves. In December (the flowering and fruiting season), hydroxyanthracene derivatives were accumulated more in the flowers (2.21% w/w) and the pods (1.82% w/w), respectively⁵¹. The method and temperature of drying markedly affected the hydroxyanthracene derivative content⁵¹. Hauptmann and Lacerda-Nazário (1950) isolated rhein (Fig. 2) (1,8-dihydroxyanthraquinone-3-carboxylic acid) from alcoholic extract of *C. alata* leaves by providing two different treatments (a) fractional precipitation with lead acetate and (b) by hydrolysis with sodium carbonate along with reported hydroxyl methyl anthraquinones or chrysophanic acid⁵². Some known anthraquinones and its derivatives (Table 2) are also reported from roots, pods, seeds, and stems of *C. alata*^{30,53-56}.

Cassia angustifolia Vahl

Cassia angustifolia Vahl (syn. *Cassia senna* Linn.) is traditionally known as Tinnevely senna; it is a fast growing and spreading Indian shrub of which seeds, pods and leaves are extensively used for pharmaceutical applications⁵⁷. It is a reputed drug in Unani medicine, which has also been adopted by the pharmacopoeias of the world⁵⁸. It is valued as a medicine for its cathartic properties and is especially useful in habitual constipation. Its leaves and pods are traditionally used as purgatives. The main purgative constituents in the leaves are anthraquinone derivatives and their glucosides⁵⁸.

The species is widely used as a laxative, although potential side effects, such as toxicity and genotoxicity, have been reported⁵⁹. Aqueous extract of the plant produces single and double strand breaks in plasmid DNA in a cell free system⁵⁹. On the other hand, it was not cytotoxic or mutagenic to *Escherichia coli* strains tested, but pointing to a new antioxidant/antimutagenic action of aqueous extract⁵⁹. Leaves of the plant are used as a safe laxative and stop bleeding⁶⁰. The active constituents of the plant are the anthranoids that are present in the leaf as dianthrone (75-80%) and as anthrones (20-25%)⁶¹. The amount of anthranoids of the emodin (Fig. 5) and aloe-emodin (Fig. 4) type is generally higher in the leaves than in the fruits⁶¹. Leaves of *C. angustifolia* also afford a significant hepatoprotective action⁶².

Various anthraquinones and its glycosides (Table 2) are reported from different parts of *C. angustifolia*^{30,36,56,58,61-68}. Mehta and Laddha (2009) had estimated amount of anthraquinone glycoside in leaves and pods of this plant. The leaves and pods of *C. angustifolia* contain not less than 2.5% of anthraquinone glycosides mainly senosides A and B, that are dianthrone glucosides derived from rhein (Fig. 2) and aloe-emodin. This makes the leaf an important source of rhein, which is currently subject of interest because of its antiviral, antitumor and antioxidant properties⁶⁵. Rhein also serves as starting compound for the synthesis of diacerein (Fig. 10), which has anti inflammatory effects and is useful in osteoarthritis⁶⁵. Aqueous extracts of the leaves of *C. angustifolia* is used as laxative and remedy for scabies and itching⁶⁶. Senoside A (Fig. 11) and B (Fig. 12) also reported in seedlings of the plant and found to inhibit bovine serum monomine oxidase activity⁶⁶. Senoside A and B content in leaves have been determined as 0.59 and 0.72%, respectively⁵⁶. El-Gengaihi *et al* (1975) reported that the percentage of anthraquinone glycosides in senna decreases with the increase in area and age of leaves and pods, the decrease being sharp at maturity⁶⁸.

Table 2 — Anthraquinone derivatives reported from *Cassia* species—Contd.

<i>Cassia</i> species	Plant part and reported anthraquinones	Ref. No.
<i>C. absus</i>	Roots: chrysophanol (Fig. 1), aloe-emodin (Fig. 4)	34
<i>C. acutifolia</i>	Root: chrysophanol (Fig. 1), physcion (Fig. 3), emodin (Fig. 5), aloe-emodin (Fig. 4), rhein (Fig. 2), sennidin C, glucorhein, chrysophancin, gluco-aloe-emodin, emodin-8-O- β -D-glucoside, Leaves & pod : gluco aloe-emodin, rhein-8-monoglucoside (Fig. 6), aglycone sennidin (Fig. 7)	35
<i>C. alata</i>	Leaves : aloe-emodin (Fig. 4), chrysophanic acid, chrysophanol (Fig. 1), isochrysophanol, emodol, rhein (Fig. 2), physcion glucoside, 4,5-dihydroxy-1-hydroxy-methylanthrone and 4,5-dihydroxy-2-hydroxy methylanthraquinone	36 30,43-46, 51, 52
	Pods: aloe-emodin (Fig. 4), emodin (Fig. 5), rhein (Fig. 2)	30
	Seeds: chrysophanol (Fig. 1), 2-hydroxy methylanthraquinone	30
	Roots:1,3,8-Trihydroxy-2- methylanthraquinone, 1,5-dihydroxy-8-methoxy-2-methylanthraquinone-3-O-D-(+)-glucopyranoside, rhein (Fig. 2), aloe-emodin (Fig. 4), emodin (Fig. 5), chrysophanol (Fig. 1), physcion (Fig. 3)	30,53
	Stems: 1,5,7-trihydroxy-3-methylanthraquinone (Fig. 8) (alatinone), 2-formyl-1,3,8-trihydroxy-anthraquinone (Fig. 9) (alatonal)	54-56
<i>C. angustifolia</i>	Leaves : aloe-emodin (Fig. 4), its 8-glucoside, aloe-emodin dianthraone, chrysophanol (Fig. 1), emodin 8-O-sophoroside, rhein (Fig. 2), rheum-emodin glycoside, aloe-emodin dianthraone diglucoside, sennoside A (Fig. 11), sennoside B (Fig. 12), sennoside C (Fig. 13) and sennoside D (Fig. 14), sennoside G,III,A ₁ , anthranoids of the emodin (Fig. 5) and aloe-emodin (Fig. 4)	30,36, 56,58, 61-63, 65-68
	Pods: aloe-emodin, chrysophanol, rhein and their glucosides, emodin anthranoids of the emodin and aloe-emodin, sennoside A,B & sennoside A ₁	30,36, 65,68
	Callus cultures from cotyledons: chrysophanol, physcion (Fig. 3), rheum emodin, aloe-emodin and rhein	64
	Seedlings & roots: several mono- and di-glucosides of anthrones, chrysophanol, physcion, emodin, aloe-emodin, rhein, chrysophanein, physcionin, gluco-aloe-emodin, emodin-8-O- β -glucoside, gluco-rhein, sennoside A,B, C	30,66
<i>C. auriculata</i>	Leaves: emodin (Fig. 5)	30
	Seed: 1,5,8-trihydroxy-6-methoxy-2-methylanthraquinone-3-O- β -D-galactopyranosyl(1 \rightarrow 4)-O- β -D-mannopyranoside	56
	Heartwood: 3-hydroxy-6,8-dimethoxy-2-methyl anthraquinone-1-O- β -D-galactoside	81
	Pod husk: rubiadin (Fig. 16), chrysophanol (Fig. 1), emodin	82
<i>C. biflora</i>	Flower: chrysophanol (Fig. 1), physcion (Fig. 3) and luteolin	83
<i>C. didymobotrya</i>	<i>In vitro</i> cultures: 7-acetylchrysophanol, chrysophanol-physcion-10,10'-bianthrone Leaves: chrysophanol (Fig. 1), aloe-emodin (Fig. 4), rhein (Fig. 2)	85 30,86
	Pods: didyronic acid, chrysophanol, physcion (Fig. 3)	56,87
<i>C. fistula</i>	Wood: rhein (Fig. 2), chrysophanol (Fig. 1)	30
	Leaves: rhein, rhein glucoside, sennoside A (Fig. 11) & sennoside B (Fig. 12), chrysophanol and physcion (Fig. 3)	88,100, 106,107
	Fruit pulp: rhein, rhein glucoside, Fistulic acid (Fig. 17), sennosides A & B	30,101
	Seeds: chrysophanol and chrysophanein	102,103
	Stem bark: rhein glycoside, 1,8-dihydroxy-6-methoxy-3-methyl anthraquinone	104,105
	Flowers: rhein, rhein glycoside, fistulin, fistulin rhamnoside	108,109
	Pods: Fistulic acid, 3-formyl-1-hydroxy-8-methoxyanthraquinone (Fig. 18), rhein and sennidin (Fig. 7), aloin, emodin (Fig. 5), sennosides, and aloe-emodin (Fig. 4)	110-114
	Roots and roots bark: Rhamnetin-3-O-gentiobioside, emodin, chrysophanic acid fistuacacidin, barbaloin and rhein	88,115
<i>C. garrettiana</i>	Heartwood: cassialoin (10-hydroxy-10-C-D-glucosylchrysophanol-9-anthrone), chrysophanol (Fig. 1), chrysophanol benzanthrone, and chrysophanol dianthrone	116-118
<i>C. glauca</i>	Bark: 1,8-dihydroxy-6-methoxy-3-methylanthraquinone	123
	Stems: chrysophanol (Fig. 1) and physcion (Fig. 3), 8-hydroxy-6-methoxy-3-methylanthraquinone-1-O- α -L-rhamnopyranosyl-(1 \rightarrow 6)- β -D-glucopyranoside	56, 124
	Leaves: emodin (Fig. 5)	125
<i>C. grandis</i>	Pods: 1,3,4-trihydroxy-6,7,8-trimethoxy-2-methyl anthraquinone-3-O- β -D-glucopyranoside	129
	Stems: emodin-9-anthrone	130
	Seeds: chrysophanol (Fig. 1), 1,2,4,8,-tetrahydroxy-6-methoxy-3-methylanthraquinone-2-O- β -D-glucopyranoside, 3-hydroxy-6,8-dimethoxy-2-methylanthraquinone-3-O- β -D-glucopyranoside and 1,3-dihydroxy-6,7,8-trimethoxy-2-methylanthraquinone-3-O- β -D-glucopyranoside	30,56 131
	Leaves: aloe-emodin (Fig. 4)	

Contd.

Table 2 — Anthraquinone derivatives reported from *Cassia* species—Contd.

<i>Cassia</i> species	Plant part and reported anthraquinones	Ref. No.
<i>C. greggii</i>	Roots: 5-hydroxy-1,4,6,7-tetramethoxy-2-methylanthraquinone, 1,5,7-trihydroxy-4,6-dimethoxy-2-methylanthraquinone, 5,6-dihydroxy-1,4,7-trimethoxy-2-methylanthraquinone, 1-hydroxy-4,7-dimethoxy-5,6-methylenedioxy-2-methylanthraquinone, 5,7-dihydroxy-1,4,6-trimethoxy-2-hydroxymethylanthraquinone, 4,5-dihydroxy-1,6,7-trimethoxy-2-methylanthraquinone, and 5,6-dihydroxy-4,7-dimethoxy-2-methylanthraquinone	132
<i>C. hirsuta</i>	Seeds: 4,4'-bis(1,3,8-trihydroxy-2-methyl-6-methoxy anthraquinone) (Fig. 19)	136
<i>C. italica</i>	Herb: aloe-emodin (Fig. 4), chrysophanol (Fig. 1), emodin (Fig. 5), emodin rhamnoside, Physcion (Fig. 3), its glucosylrhamnoside Leaves and pods: aloe-emodin, chrysophanol, rhein (Fig. 2), sennidins A & B, Sennoside A (Fig. 11) and B (Fig. 12), 1,5-dihydroxy-3-methyl anthraquinone	30 30,67, 142
<i>C. javanica</i>	Root: emodin-8-rhamnoside; 5-hydroxyemodin-8-rhamnoside (Fig. 20), 1,3-dihydroxy-5,6,7-trimethoxy-2-methyl anthraquinone, 1,4-dihydroxy-8-methoxy-2-methylanthraquinone-3-O-β-D-glucopyranoside, 1,8-dihydroxy-6,7-dihydroxy-2-methyl anthraquinone Leaves: quercetin, emodin (Fig. 5) rhein (Fig. 2), chrysophanic acid, aloe-emodin (Fig. 4), chrysophanol (Fig. 1), physcion (Fig. 3) and its glucoside Seeds: chrysophanol, physcion, 1,5-dihydroxy-4,7-dimethoxy-2-methylanthraquinone-rhamnopyranoside, 1,3,6,7,8-pentahydroxy-4-methoxy-2-methylanthraquinone Stem bark: 1,2-dihydro-1,3-dihydroxyl,6,8-dimethoxy-2-methyl-anthtraquinone, 1,3,5,8-tetrahydroxy-6-methoxy-2-methyl-anthraquinone (Fig. 21), 1,3,4,6-tetrahydroxy-5,8-dimethoxy-2-methylanthraquinone, 1,4-dihydroxy-6,7,8-trimethoxy-2-methylanthraquinone, 1-hydroxy-3,6,7,8-tetramethoxy-2-methyl-anthraquinone, 4,4'-bis(1,5-dihydroxy-7-hydroxymethyl-2-methyl-3-methoxy) anthraquinone	67,145, 146,151 30,86, 147 30 56,148-150
<i>C. kleinii</i>	Aerial parts and roots: kleinioxanthrone-1,2,3,4	156,157
<i>C. laevigata</i>	Roots: physcion-8-galactoside; emodin (Fig. 5), physcion (Fig. 3) Seeds: chrysophanol (Fig. 1), physcion Pods: physcion-8-galactoside, chrysophanol, 1,8-dihydroxy-6-methoxy-3-methyl-anthraquinone, 1-hydroxy-6-methoxy-3-methylanthraquinone-8-O-β-D-galactosyl (1→4)O-β-D-galactopyranoside Leaves: physcion, 5,7'-biphyscion (floribundone 1) (Fig. 22) and 5,7'-physcion-physcionanthrone (floribundone 2) (Fig. 23), chrysophanol, emodin, 1,8-dihydroxy-6-methyl-3-methyl anthraquinone	163 30 30,164 165
<i>C. marginata</i>	Seeds: chrysophanol (Fig. 1), physcion (Fig. 3), 1,3-dihydroxy-2-methylanthraquinone-8-O-α-L-arabinopyranoside, 1,3-dihydroxy-6,8-dimethoxy-2-isoprenylantraquinone, physcion-8-O-α-L-xylopyranoside, emodin-8-O-α-L-arabinopyranoside 1,3-dihydroxy-6,8-dimethoxyanthraquinone (Fig. 24) Root: 4,4'-bis(1,3-dihydroxy-6,8-dimethoxy-2-methylanthraquinone-3-O-rhamnosyl-(1→6)-glucopyranoside (Fig. 25) and 1,3,5,8-tetrahydroxy-2-methyl-anthraquinone 3-O-glucoside (Fig. 26) Flower: 1,8-dihydroxy-3-carbo(β-D-glucopyranosyloxy)- anthraquinone Leaves: 1,2-dihydroanthraquinone, roxburghinol, chrysophanol, physcion, rhein (Fig. 2) Wood: roxburghinol, chrysophanol	30,169, 170 171 30 30,67, 172
<i>C. mimosoides</i>	Leaves: emodin (Fig. 5), its glycoside Root: physcion (Fig. 3) Seeds: emodin, emodic acid, physcion Aerial parts: chrysophanol (Fig. 1), 1,8-dihydroxy-6-methoxy-2-methyl anthraquinone (Fig. 28) and 1,8-dihydroxy-6-methoxy-3-methyl anthraquinone (Fig. 29)	30 30 30, 173
<i>C. multijuga</i>	Seeds: 1,3,8-trihydroxy-2-methyl anthraquinone, 1,3-dihydroxy 6,8-dimethoxy-2-methyl anthraquinone, 3-hydroxy-6,8-dimethoxy-2-methyl anthraquinone-1-O-β-D(+) glucopyranoside and 3-hydroxy 6,8-dimethoxy-2-methyl anthraquinone 1-O-rhamnopyranosyl (1→6) glucopyranoside (rutinoside) Roots: 1,3-dihydroxy-2-methyl anthraquinone, 1,3-dihydroxy 6,8-dimethoxy-2-methyl anthraquinone, 1,3,8-trihydroxy-6-methoxy 2-methyl anthraquinone, 1,8-dihydroxy-2-methylanthraquinone-3-O-rutinoside, 1-hydroxy-6,8-dimethoxy-2-methylanthraquinone-3-O- rutinoside, 1,8-dihydroxy-6-methoxy-2-methylanthraquinone-3-O- rutinoside,	174 30
<i>C. nigricans</i>	Whole plant: 1,3,8-trihydroxy-6-methyl-9,10-anthracenedione, 4-hydroxy-anthraquinone-2-carboxylic acid Leaves: emodin (Fig. 5), citreorosein (Fig. 30) and emodic acid (Fig. 31) Leaves & pods: Emodol, emodol anthrone	176,178 179,180 30
<i>C. nomame</i>	Seeds: Physcion (Fig. 3), physcion-9-anthrone, emodin-9-anthrone, and physcion 10,10-bianthrone Aerial parts: chrysophanol (Fig. 1), physcion and emodin (Fig. 5)	182
<i>C. obtusa</i>	Roots: 1-3-dihydroxy-6-methoxy-7-methylanthraquinone and 1,3-dihydroxy-3,7-diformylantraquinone	184
<i>C. obtusifolia</i>	Seeds: aloe-emodin (Fig. 4), 1-methylaurantio-obtusin-2-O-β-d-glucopyranoside, emodin (Fig. 5), 1,2-dihydroxyanthraquinone, obtusin, chrysoobtusin, aurantioobtusin, gluco-obtusifolin, gluco-aurantioobtusin, gluco-chryso-obtusin, 1-desmethylaurantio-obtusin, 1-desmethylaurantio-obtusin-2-O-β-D-glucopyranoside, 1-desmethylchryso-obtusin, 1-desmethyl-obtusin, aurantio-obtusin-6-O-β-D-	30,36, 67,191, 193-202 67

Contd.

Table 2 — Anthraquinone derivatives reported from *Cassia* species—Contd.

<i>Cassia</i> species	Plant part and reported anthraquinones	Ref. No.
	glucopyranoside, alaternin-1-O-β-D-glucopyranoside (Fig. 32), chrysoobtusin-2-O-β-D-glucopyranoside, physcion-8-O-β-D-glucoside, obtusifolin, O-methyl-chrysophanol, emodin-1-O-β-gentio-bioside, chrysophanol-1-O-β-gentiobioside, physcion-8-O-β-gentiobioside, physcion-8-O-β-glucoside, chrysophanol-1-O-β-D-glucopyranosyl-(13)-β-D-glucopyranosyl-(1→6)-β-D-glucopyranoside, chrysophanic acid, physcion (Fig. 3), questin, 1,3-dihydroxy-8-methylanthraquinone, chrysophanol-10,10'-bianthrone, torosachryson, Leaves: emodin	30,67, 192,203
	Roots: O-methyl-chrysophanol, aloe-emodin, chrysophanol (Fig. 1), physcion (Fig. 3), 1-hydroxy-7-methoxy-3-methylanthraquinone, 8-O-methylchrysophanol, 1-O-methylchrysophanol and 1,2,8-trihydroxy-6,7-dimethoxyanthraquinone, emodin, iso-landicin, helminthosporin, obtusifolin, xanthorin	
<i>C. occidentalis</i>	Leaves: chrysophanol (Fig. 1), emodin (Fig. 5), their glycosides, physcion (Fig. 3), bianthraquinones	30
	Roots: emodin, 1,8 dihydroxy anthraquinone, quercetin, chrysophanol, emodol, physcion, Islandicin, questin, chrysophanol-10,10'-bianthrone, germichryson, rhein (Fig. 2), aloe-emodin (Fig. 4), their glycosides, α-hydroxyanthraquinone	30,36, 67,213, 214,216
	Seeds: chrysophanol, physcion, their glycosides, aloe-emodin, emodin, rhein, 1,8-dihydroxy-2-methylanthraquinone, 1,4,5-trihydroxy-7-methoxy-3-methylanthraquinone, 1-Glucoside-3-Methyl-6-methoxy-1,8-dihydroxy-anthraquinone	30,215, 216 67
	Callus culture: 7-methylphyscion, 7-methyltorosachryson	30
	Flowers: emodin, physcion & its glucoside	
<i>C. podocarpa</i>	Leaves: rhein (Fig. 2) & its glucoside, emodin (Fig. 5), chrysophanol (Fig. 1), rhein-anthroneglucoside, sennoside A (Fig. 11) & sennoside B (Fig. 12)	30,219-221
	Pods: rhein & its glucoside, rhein-anthroneglucoside, sennoside A & sennoside B	30
	Callus culture: rhein and chrysophanol	31
<i>C. pudibunda</i>	Roots: chrysophanol dimethyl ether, chrysophanol (Fig. 1), physcion (Fig. 3),	223
<i>C. pumila</i>	Whole Plant: emodin (Fig. 5), chrysophanol (Fig. 1), physcion (Fig. 3), sennosides	30,224
<i>C. racemosa</i>	Stem bark: racemochryson (Fig. 34), chrysophanol (Fig. 1), physcion (Fig. 3)	225,226
<i>C. renigera</i>	Leaves: chrysophanol (Fig. 1), physcion (Fig. 3), rhein (Fig. 2)	30
	Stem bark: 1-hydroxy-3,8-dimethoxy-2-methylanthraquinone, 1,5,6-trihydroxy-3-methyl-anthraquinone-8-O-α-L-glucoside	30,227
	Seeds: 1,8-dihydroxy-3,5,7-trimethoxy-2-methylanthraquinone, 1,5,8-trihydroxy-6,7-dimethoxy-2-methylanthraquinone-3-O-α-L-rhamnopyranosides, 1-hydroxy-8-methoxy-2-methylanthraquinone	30
<i>C. reticulata</i>	Leaves: emodin (Fig. 5), chrysophanic acid	228
	Flowers: rhein (Fig. 2) and aloe-emodin (Fig. 4)	229,230
<i>C. siamea</i>	Leaves: cassiamin A (Fig. 35), chrysophanol (Fig. 1), physcion (Fig. 3), rhein (Fig. 2), sennosides	30
	Heartwood: 4,4'-bis(1,3-dihydroxy-6,8-dimethoxy-2-methylanthraquinone), cassiamin A, 1,1'-bis(4,5-dihydroxy-2-methyl anthraquinone), chrysophanol, emodin (Fig. 5)	30,233 30,36,
	Stem bark: chrysophanol, cassiamin A, B & C, physcion, siameanin, siameadin, rhein	56,105
	Root bark: 1,1',3,8,8'-pentahydroxy-3',6-dimethyl[2,2'-bianthracene]-9,9',10,10'-tetrone, 7-chloro-1,1',6,8,8'-pentahydroxy-3,3'-dimethyl[2,2'-bianthracene]-9,9',10,10'-tetrone, chrysophanol (1), cassiamin A, emodin, cassiamin B (Fig. 36)	234-236
	Root: 1-hydroxy-6,8-dimethoxy-2-methylanthraquinone-3-O-rutinoside, 1,5,8-trimethoxy-2-methylanthraquinone-3-O-β-D-galactopyranoside	56
<i>C. singueana</i>	Root: torosachryson, germichryson, singueanol-I, singueanol-II, 7-methylphyscion, cassiamin A	240,241
<i>C. sophera</i>	Leaves: sennoside Flower: chrysophanol (Fig. 1)	30
	Root bark: 1,8-dihydroxy-2-methylanthraquinone 3-neohesperidoside, chrysophanol, physcion (Fig. 3), 1,8-dihydroxy-3,6-dimethoxy-2-methyl-7-vinylanthraquinone, 1,3-dihydroxy-5,7,8-trimethoxy-2-methylanthraquinone	243, 245
	Heartwood: 1,2,7-trihydroxy-6,8-dimethoxy-3-methyl-anthraquinone, 1,2,6-trihydroxy-7,8-dimethoxy-3-methylanthraquinone, chrysophanol, physcion, emodin (Fig. 5), sopheranin	30,244
<i>C. spectabilis</i>	Leaves: chrysophanol (Fig. 1), physcion (Fig. 3), 1,3,8-trihydroxy-2-methylanthraquinone	30
	Flower buds: chrysophanol and 1,8-dihydroxy-6-methoxy-3-methyl-anthraquinone	247
<i>C. tomentosa</i>	Whole plant: senglone (Fig. 37), emodin (Fig. 5), floribundone 1(Fig. 22)	56
<i>C. tora</i>	Seeds: Chrysoobtusin, aurantio-obtusin, obtusin, chryso-obtusin-2-O-β-D-glucoside, physcion (Fig. 3), emodin, chrysophanol (Fig. 1), obtusifolin, and obtusifolin-2-O-β-D-glucoside, rhein (Fig. 2), 1-methylaurantio-obtusin, 1-methylchryso-obtusin, 1-[(β-d-glucopyranosyl-(1→3)-O-β-d-glucopyranosyl-(1→6)-O-β-d-glucopyranosyl)oxy]-8-hydroxy-3-methyl-9,10-anthraquinone, 1-[(β-d-glucopyranosyl-	30,248, 257,261-269, 271-276

Contd.

Table 2 — Anthraquinone derivatives reported from *Cassia* species —Contd.

<i>Cassia</i> species	Plant part and reported anthraquinones	Ref. No.
<i>C. tora</i>	(1→6)-O-β-d-glucopyranosyl-(1→3)-O-β-d-glucopyranosyl-(1→6)-O-β-d-glucopyranosyl]oxy]-8-hydroxy-3-methyl-9,10-anthraquinone and 2-(β-d-glucopyranosyloxy)-8-hydroxy-3-methyl-1-methoxy-9,10-anthraquinone, alaternin 2-O-β-d-glucopyranoside, alaternin, aloe-emodin (Fig. 4), chrysophanic acid & its 9-antrone, 8-hydroxy-3-methylanthraquinone-1-β-gentiobioside, rubrofusarin & its 6-β-gentiobioside, nor-rubrofusarin, torachryson Leaves: aloe-emodin, 1,8-dihydroxy-3-hydroxymethylanthraquinone, emodin (Fig. 5) Roots: 1,3,5-trihydroxy-6,7-dimethoxy-2-methylanthraquinone Stem: rhein (Fig. 2), 1-hydroxy-5-methoxy-2-methyl anthraquinone & its glycoside, 5-methoxy-2-methyl anthraquinone-1-O-α-L-rhamnoside, chrysophanol, emodin	30,270 30 30,277
<i>C. torosa</i>	Seedlings: phlegmacin, anhydrophlegmacin-9,10-quinone, germichryson, germitosone, methylgermitosone Seeds: Torosachryson, physcion-9-anthrone, physcion-10,10'-bianthrone, anhydrophlegmacinB ₂ [2-(6'-methoxy-3'-methyl-3',8',9'-trihydroxy-1'-oxo-1',2',3',4'-tetrahydroanthracene-10'-yl)-1,8-dihydroxy-3-methoxy-6-methyl-9-oxo-9,10-dihydroanthracene] and torosanin [2-(6'-methoxy-3'-methyl-3', 8',9'-trihydroxy-1'-oxo-1',2',3',4'-tetrahydroanthracene-5'-yl)-1, 8-dihydroxy-3-methoxy-6-methyl-9-oxo-9,10-dihydroanthracene], torosachryson 8-β-D-gentiobioside, physcion 8-β-D-gentiobioside, physcion (Fig. 3), xanthorin and emodin (Fig. 5) Flowers: torosaol-III, physcion, 5,7'-physcionanthrone-physcion, 5,7'-biphyscion, torosanin-9,10-quinone, 5,7-dihydroxy-chromone, naringenin, chrysoeriol Roots: torosaols I and II Leaves: toroside A	278,279,281 280,282,283 285 284,286

***Cassia auriculata* Linn.**

It is commonly known as Tanner's cassia, a common plant in Asia, has been widely used in traditional medicine as cure for rheumatism, conjunctivitis and diabetes⁶⁹. It is the source of yellow coloured dye, obtained from its flowers and seeds⁷⁰. The leaves are bitter, astringent, acrid, thermogenic, haematinic, constipating and expectorant. Seeds are also bitter, astringent, acrid, cooling, ophthalmic, diuretic, alexeteric and vulnerary⁷¹. Various parts of the plant have been reported to possess a number of therapeutic activities to manage disease states like leprosy, asthma, gout, rheumatism and diabetes⁷¹. It is also used as antipyretic, antiulcer and in the treatment of skin infections⁷¹.

In folk remedies of India, its flowers are proposed to have antidiabetic activity⁷². Leaves of *C. auriculata* are having potential in the development of drug for diabetes due to its antihyperglycemic and lipid-lowering activity⁷³. *C. auriculata* exerts a strong antihyperglycemic effect in rats comparable to the therapeutic drug Acarbose⁷⁴. Aqueous leaf extract was found to lower the serum glucose level, and also found to inhibit the body weight reduction induced by alloxan administration⁷⁵.

The ethanolic extract had nephroprotective effect and the probable mechanism of nephroprotection by *C. auriculata* against cisplatin and gentamicin induced renal injury could be due to its antioxidant and free-radical-scavenging property⁷⁶. The ethanol

and methanol extracts of flowers showed antioxidant activity⁷⁷. The leaf extract has potential to reduce the liver injury caused by alcohol⁷⁸. Supplementation with leaf extract can offer protection against free radical mediated oxidative stress in experimental hepatotoxicity⁷⁸. In addition, histopathological studies of the liver and brain confirmed the beneficial role of leaf extract⁷⁸. *C. auriculata* tea has the potential to influence the bioavailability of carbamazepine, and hence its therapeutic actions⁷⁹.

Prasanna *et al* (2009) evaluated the *in vitro* anti-cancer effect of *C. auriculata* leaf extract (CALE) in human breast adenocarcinoma MCF-7 and human larynx carcinoma Hep-2 cell lines. The results showed the anti-cancer action is due to nuclear fragmentation and condensation, associated with the appearance of A(0) peak in cell cycle analysis that is indicative of apoptosis. These results demonstrated that CALE inhibits the proliferation of MCF-7 and Hep-2 cells through induction of apoptosis, making CALE a candidate as new anti-cancer drug⁸¹. Above mentioned therapeutic action of *C. auriculata* can be correlated with presence of emodin³⁰ however not studied in detail. Presence of anthraquinones in other parts of plant (Table 2) is also reported^{56,81,82}.

***Cassia biflora* Linn.**

It is a medium size shrub which flowers profusely. Hemlata and Kalidhar (1995) reported presence of chrysophanol (Fig. 1), physcion (Fig. 3) and luteolin in the plant⁸³.

***Cassia didymobotrya* Fresen.**

It is a evergreen shrub, native to East Africa. It can tolerate full sun and grows with little water. A 23-kDa thaumatin-like protein isolated and purified from *C. didymobotrya* cell cultures shown antifungal activity⁸⁵.

Presence of chrysophanol (Fig. 1) along with various anthraquinones (Table 2) is reported from different parts of this species^{30,56,85-87}.

***Cassia fistula* Linn.**

Cassia fistula Linn. (Hindi-Amaltas, English-Golden shower, Indian Labernum and Lantern tree in Thailand) is a semi-wild slender tree, with moderate to fast growth⁸⁸. It is a native of India, the Amazon and Sri Lanka and extensively diffused in various countries including Mauritius, South Africa, Mexico, China, West Indies, East Arica and Brazil as an ornamental plant and widely cultivated as an ornamental tree for its beautiful bunches of yellow flowers⁸⁹. It is highly reputed for its strong laxative and purgative properties. In Ayurvedic medicine, it is used against various disorders such as haematemesis, pruritus, leucoderma and diabetes⁹⁰. The antipyretic, analgesic effect of *C. fistula* has also been reported, together with its antifungal, antibacterial and anti-inflammatory activities⁹¹⁻⁹³. The plant extract is also recommended as a pest control agent⁹³. These effects have been mainly attributed to the presence of alkaloids, triterpene derivatives, anthraquinone derivatives, and polyphenolics comprising flavonoids, catechins and proanthocyanidins⁹³.

Different parts of the plant have been demonstrated to possess several medicinal values such as antitumor⁹⁴, antioxidant⁹³⁻⁹⁵ and hypoglycemic⁹⁶ activities. In Thai traditional medicines, the ripe pods have been used as a laxative drug by boiling with water and the mixture is filtered through a muslin cloth. The filtrate is evaporated and the soft extract is made as small pills⁹⁷.

C. fistula, is an important constituent in the traditional medicine in India and possesses properties useful in the treatment of inflammatory diseases, skin diseases, rheumatism, ulcers, anorexia, jaundice, and as laxatives⁹⁸. Root of the tree is also used as a laxative, useful in fever, heart disease, retained excretions, biliousness, etc.⁹⁹. The pulp of fruits of *C. fistula* is lenitive, useful for relieving thoracic obstructions and heat of blood and is a safe aperient for children and women⁹⁹. The leaves are also found effective against cough and ringworm infections⁹⁰. The active principles are known to be anthraquinone

glycosides of which rhein, sennoside and aloe-emodin are major components⁹⁷. Extensive studies have been carried out during the past few decades on isolation and characterisation of anthraquinones (Table 2) from various parts of the species^{30,88,100-115}. The anthraquinone glycosides remain high in the mature and old leaves in the months from January to April when the contents of mature pods are low. In the developing green pods the content is high compared to the older ones, while the young leaves have lower glycosidal content compared to their mature stage¹⁰⁰.

***Cassia garrettiana* Craib**

Cassia garrettiana Craib, known in Thai as Samae-sarn, is a small tree, up to 10 m high with alternate even-pinnate, leaves. In Thai traditional medicine, the heartwood of this plant is used to cure feminine diseases and as blood tonic for women. *C. garrettiana* has been reported to show many biological activities such as anticancer, antifungal, acid secretion inhibitor, anti-allergy and antihypertensive activities, and used as mild cathartics¹¹⁶. The heartwood of the plant with above mentioned properties afford a new anthrone-c-glycoside named cassialoin (10-hydroxy-10-C-D-glucosylchrysophanol-9-anthrone) together with other anthraquinones (Table 2) as well as various phenolic compounds¹¹⁷. Cassialoin (5 and 10 mg/kg) inhibited tumor growth and metastasis to the abdomen and the expression of CD31 (angiogenesis marker) in the tumors, and it increased the numbers of the γ -interferon (IFN- γ)-positive, CD8⁺T and natural killer cells in the small intestine or spleen of colon 26-bearing mice¹¹⁸. Furthermore, cassialoin inhibited tumor-induced angiogenesis in colon 26-packed chamber-bearing mice¹¹⁸. These antitumor and antimetastatic actions of cassialoin may be partly due to cassialoin and its metabolites such as chrysophanol-9-anthrone and aloe-emodin through their anti-angiogenic activities and/or the modulation of the immune systems in the spleen and small intestine in tumor-bearing mice¹¹⁸.

C. garrettiana was investigated for its active constituents against HIV-1 protease (HIV-1 PR). Tewtrakul *et al* (2007) carried out bioassay-guided fractionation of the heartwood of this plant which led to the isolation of a stilbene derivative piceatannol and an anthraquinone derivative chrysophanol. This pigment showed significant HIV-1 protease inhibitory activity whereas its related anthraquinone derivatives emodin, aloe-emodin and rhein were inactive¹¹⁶.

***Cassia glauca* Lam.**

Cassia glauca Lam. (syn. *Cassia surattensis* Burm. f.) is an evergreen shrub that grows about 3 m high with ovate, pointed leaflet. Aerial parts of the plant are used as a central nervous system depressant, purgative, antimalarial and as a diuretic¹¹⁹. The bark and leaves have been used in diabetes for lowering blood glucose level and gonorrhea in the Ayurvedic system of medicine¹¹⁹. Acetone extract of *C. glauca* shows significant antidiabetic activity¹²⁰ while *C. glauca* bark extracts have hypoglycemic potential of ameliorating the diabetic conditions in diabetic rats¹²¹. The phytochemical investigation of plant shows the presence of γ -sitosteroline, fatty acids, anthraquinones, tannis, and alkaloids and a water soluble biopolymer composed of D-galactose and D-mannose in molar ratio 1:3^(Refs 119,122). Anthraquinones (Table 2)^{56,123-125} have been isolated and characterized from bark and stem whereas Gritsanapan and Nualkaew (2002) estimated the content of total anthraquinone glycosides and total anthraquinones in the leaves using UV-vis spectrophotometric method and reported 0.02-0.03% and 0.03-0.06% (dry wt), respectively. The variation of both anthraquinone glycosides and total anthraquinones in the leaves collected from several areas and seasons were not significantly different. The content of emodin, a major anthraquinone from glycosidic fraction, was 0.0003-0.0017% dry weight when determined by TLC densitometric method¹²⁵.

***Cassia grandis* Linn f.**

Cassia grandis Linn f. known as Coral shower, Apple blossom cassia, Pink shower, Liquorice tree or Horse cassia is a medium-sized tree, up to 20-30 m tall, found in abundance throughout India. Its seeds contain about 50% endosperm gum and possess the characteristics of becoming a potential source of seed gum^{126,127}. The ethanol extract of the leaves and bark showed *in vitro* antifungal activity against *Epidermophyton floccosum*, *Microsporium gypseum* and *Trichophyton rubrum* in pure culture at a minimal inhibitory concentration of 50 μ g/ml⁸⁹. This plant has significant anti-inflammatory and analgesic properties¹²⁸. Anthraquinones (Table 2) are reported from its stem, pods and seeds^{30,56,129-131}. Due to presence of anthraquinones it is especially used as a purgative in veterinary practice³⁰.

***Cassia greggii* Gray**

Cassia greggii Gray is a small tree having 3-5-foliolate 1cm long leaves and leaflets oblong-oval, slightly truncate. Gonza'lez *et al* (1992) have isolated

seven new anthraquinones (Table 2) from the dichloromethane extract of its roots. Their structures were elucidated on the basis of spectral data¹³².

***Cassia hirsuta* Linn. syn. *Senna hirsuta* (Linn.) H.S. Irwin & Barneby**

A diffuse shrub widely distributed in the hilly tracts of South India¹³³. *C. hirsuta*, commonly known as 'Stinking cassia' is used for the local treatment of liver ailments and is an important ingredient of polyherbal formulations marketed for liver diseases¹³⁴. The main effects of the *C. hirsuta* leaves extract could be both preventive and therapeutic¹³⁴. Ethanolic leaf extract has significant hepatoprotective effect¹³⁴, and used for stomach troubles, dysentery, abscesses, rheumatism, haematuria, fever and other diseases¹³⁵. The ethanol extract of leaf was also found to have antimicrobial activity against some pathogenic bacteria¹³⁵. The seeds contain a phytotoxin, tannin and 0.25% chrysarobin¹³⁵. Singh and Singh (1986) reported that seeds contain a new bianthraquinone, 4,4'-bis(1,3,8-trihydroxy -6-methoxy-2-methyl) anthraquinone (Fig. 19) and a triterpenoid 3 β ,16 β ,22-trihydroxyisohopane¹³⁶.

***Cassia italica* (Mill.) Lam. ex F.W. Ander**

Cassia italica (Mill.) Lam. ex F.W. Ander (syn. *Cassia obovata* Collad.) is a small shrub, with 3-12 cm long leaves, with petiole and rachis eglandular. It is used for the production of folioles from which sennosides can be extracted and used in traditional medicine for the treatment of diverse ailments¹³⁷. *C. italica* is also a rich source of flavonoids¹³⁸ and sennoside A (Fig. 11) and B (Fig. 12) (Table 2) were isolated from its leaves and pods⁶⁷.

The ethanolic extract of the whole plant parts (root, stem leaves and pods) of *C. italica* was investigated for bioactivities namely anti-inflammatory, antipyretic, analgesic, prostaglandin (PG) release by rat peritoneal leucocytes, antineoplastic and antiviral activities. In rats, the extracts reduced carrageenin-induced paw swelling (100 mg/kg bw-31%) and fever (100 mg/kg bw-37%). The extract showed weak effects on writhing induced by acetic acid. A dose-dependent inhibition of PG release effect was observed using rat peritoneal leucocytes¹³⁹. Extracts of various parts were found to contain antimicrobial activity¹⁴⁰ and crude ethanolic extract has CNS depressant properties, manifested as antinociception and sedation¹⁴¹. Kazmi *et al* (1994) carried out phytochemical studies of the leaves and reported 1,5-dihydroxy-3-methyl anthraquinone and an anthraquinone (Table 2) that possess antimicrobial and antitumour activities¹⁴².

***Cassia javanica* Linn. syn. *Cassia nodosa* Buch-Ham. ex Roxb.**

A small to medium-sized tree up to 25-40 m tall, deciduous or semi-deciduous, trunk of young trees either smooth or armed with stump-remnants of branches⁸⁸. The flowers are good source of flavonoid glycosides¹⁴³. The seed gum of *C. javanica* has rheological property¹⁴⁴. Purgative nature and haemagglutinating activity of seed extracts are main reported application of *C. javanica*, however phytochemical analysis of various parts of this plant reported presence of usual and novel anthraquinones (Table 2)^{30,56,67,86,145-151}. A new compound, nodolide, has been isolated from the flowers and characterized as (-)-7-acetoxy-9,10-dimethyl-1,5-octacosanolate¹⁵². Nodoside, also naturally occurs in its flowers¹⁵³.

***Cassia kleinii* White & Arn.**

Cassia kleinii White & Arn. is a diffused under-shrub found in partly shaded and moist places¹⁵⁴. The alcohol extract of leaf exhibited concentration dependent antihyperglycemic effect in glucose loaded rats. But the extract did not show hypoglycemic effect in fasted normal rats¹⁵⁵. The ethanol extract of leaf exhibited antidiabetic activity in streptozotocin-induced diabetic rats¹⁵⁴. Various oxanthrone esters are reported from aerial parts and roots of this plant^{156,157}.

***Cassia laevigata* Willd. syn. *Cassia floribunda* Cav.**

A shrub of 2-3 m high with yellow flowers and pinnate leaves consisting of three or four pairs of ovate leaflets. Leaves and branches are found to contain unusual fatty acids and flavonoids¹⁵⁸⁻¹⁶⁰. The seeds are found to be an important under-utilized legume seeds served as low-cost protein sources to alleviate the protein-energy-malnutrition among people living in developing countries^{161, 162}. However purgative anthraquinones along with some new anthraquinones (Table 2) reported from all the parts of *C. laevigata* including seeds^{30,163-165}.

***Cassia marginata* Linn.**

Cassia marginata Linn. (syn. *Cassia roxburghii* DC.) known as 'Red Cassia' is smaller and less robust than the other species, but is extremely beautiful at all times of the year. This is a large sized Indian tree having cylindrical and indehiscent long pods (with many seeds) containing a black cathartic pulp, used as a horse medicine¹⁶⁶. Seeds are medium in size and consist of about 50% endosperm which is responsible for yielding water soluble gum¹⁶⁷. Seed gum (8%) could be useful as binding agent especially when high mechanical strength and slower release is

concerned^{167,168}. Various anthraquinone and its derivatives (Table 2) are reported from all the parts^{30,67,169-172}.

***Cassia mimosoides* Linn.**

Cassia mimosoides Linn. (Karagain), Chiang-Mang (in Chinese.) is a low, diffuse shrub up to 1.5 m in height found in open grasslands at low and medium altitudes, in some regions ascending to 1,500 m. The roots are used as cure for diarrhoea. The young stems and leaves are dried and used as a substitute for tea in Japan¹⁷³. All the parts are found to contain anthraquinones (Table 2) along with 1,8-dihydroxy-6-methoxy-2-methyl anthraquinone (Fig. 28) and 1,8-dihydroxy-6-methoxy-3-methyl anthraquinone (Fig. 29) are reported from the aerial parts^{30,173}.

***Cassia multijuga* Rich.**

Cassia multijuga Rich. (Leafy cassia) is a medium sized legume tree, 10 to 15 m in height that frequently occurs in secondary forests, clearings, edges, regeneration areas and pastures. Leaves are used as a sedative for children. Seeds of this plant are used as a source of industrial gum. Seeds and roots contain anthraquinones and some new derivatives (Table 2) are also isolated which are not reported from any other plant source^{30,174}.

***Cassia nigricans* Vahl**

It is a herbaceous plant, apparently annual, erect, simple or branched woody herb or undershrub up to 1.2-1.5 m high with small yellow flowers that grow widely in the savannah grasslands of West Africa including Nigeria. The roots and leaves have been used medicinally in Senegal and Guinea as a substitute for quinine for many years. The root infusion is also used as a vermifuge. The pulverized leaves are employed as appetizers and febrifuge, while the leaf decoction is used in treating fevers¹⁷⁵. It is widely used for treating skin diseases such as ringworm, scabies and eczema. The aqueous extract of the leaves is used by traditional healers in Nigeria for the treatment of peptic ulcer and other gastrointestinal disorders, beside this extract is found to show good analgesic and anti-inflammatory effects¹⁷⁶. A pinch of the grounded leaves is taken with water for the treatment of peptic ulcers¹⁷⁵. The methanolic extract of leaves found to have antidiarrhoeal effect might be due to α_2 -adrenoceptor stimulation. The extract also reduced significantly the ulcers induced by both indomethacin and ethanol¹⁷⁷.

The methanolic extract also shown *in vitro* antiplasmodial activity against *P. falciparum* strain. This finding supports the traditional use of the plant for the treatment of malaria¹⁷⁸. It is commonly used in West Africa to protect grain storage from insects¹⁷⁹ which is reported due to the presence of anthraquinones in the plant (Table 2)^{30,176,178-180}.

Anthraquinones isolated from crude extract of this plant are the main anti-plasmodial principle and also have potential analgesic and anti-inflammatory activity^{176,178}. Anthraquinones emodin (Fig. 5), citreorosein (Fig. 30) and emodic acid (Fig. 31) were isolated as insecticidal principles. Emodin, the most abundant and active anthraquinone showed about 85% mortality on mosquito larvae of *Anopheles gambiaea* and adult *B. tabaci* at 50 and 25 lg/ml, respectively, in 24 h, therefore the extract of *C. nigricans* has the potential to be used as an organic approach to manage some of the agricultural pests¹⁷⁹. Emodin isolated from the ethyl acetate extract of the leaves showed significant antimicrobial activity on some common pathogens¹⁸⁰. The isolation of the emodin justifies the use of its leaves in herbal medicine for the treatment of skin diseases and gastro-intestinal disorders¹⁸⁰.

Cassia nomame (Sieb.) Honda

It is native to China and originally reported in the South of the Changjiang River. *C. nomame* extract is widely used as health food supplements, pharmaceuticals and in cosmetic preparation. It is a new source in the natural product industry to help people with weight problems by using its lipase inhibition activity to prevent the fat absorption. The aqueous extract from leaves, stems and pods called "Hama-cha" is a conventional beverage in the San-in district of Japan¹⁸¹. It is also used as a raw material for a diuretic or antidote in a folk remedy¹⁸¹. The extract has suppressing effect on clastogenicity and cytotoxicity of mitomycin C in CHO Cells¹⁸¹. Kitanaka and Takido (1985) concluded that the seeds and aerial parts of *C. nomame* are found to contain various anthraquinones (Table 2)¹⁸².

Cassia obtusa Linn.

The species consist of small herbs found in tropical and subtropical regions and have wide applications in herbal formulations. Leaf, stem and fruits are used to cure various ailments in human beings. It produces a diverse range of bioactive molecules including anthraquinones (Table 2); making them a rich source

of different types of medicines^{183,184}. It was observed that aqueous, benzene and methanol extracts of fruit exhibited inhibitory action against wide range of bacteria including Gram negative bacteria¹⁸³.

Cassia obtusifolia Linn.

Cassia obtusifolia Linn. (Sicklepod) is an annual weed with erect, nearly hairless stems. The plant and its seeds are common contaminants of agricultural commodities, are toxic to cattle and poultry. Toxicity has been attributed to anthraquinones which are major constituents of the plant¹⁸⁵. The composition of Sicklepod seed has been reported to include anthraquinones, 1-2; fats, 5-7; proteins, 14-19; and carbohydrates, 66-69% (Ref. 186). Sicklepod seed contains a gum of commercial interest in addition to protein and fat¹⁸⁷. As much as 41% of the seed was extractable¹⁸⁸. Some extracts were strong inhibitors of wheat, velvetleaf and sicklepod root growth, causing discoloration of the root meristems in a manner similar to that caused by naphthoquinones such as juglone and plumbagin¹⁸⁸. Some extracts increased weight gain in fall armyworm (*Spodoptera frugiperda*) causing them to grow to 50-100% larger than controls in a 7-day trial¹⁸⁸. Naturally occurring quinones and quinone-containing extracts of seeds affected muscle mitochondrial function¹⁸⁹. Ethanolic extract of the seeds has neuroprotective effects¹⁹⁰.

Juemingzi (seeds of *C. obtusifolia*) is a reputed laxative and tonic in Chinese medicine¹⁹¹ and has been widely used in traditional Chinese medicine for treatment of red and tearing eyes, headache and dizziness¹⁹². The herb is traditionally used to improve visual acuity and to remove "heat" from the liver and currently also used to treat hypercholesterolemia and hypertension¹⁹¹. Li *et al* (2004) reported antiseptic, diuretic, diarrhoeal, antioxidant and antimutagenic activities of *C. obtusifolia*¹⁹¹. Presence of various anthraquinone derivatives in seeds (Table 2) impart above mentioned pharmacological properties, however anthraquinones are also reported from root (Table 2)^{30,36,67,191-203}. It has been reported and confirmed that among 25 leguminous seeds, the methanol extract of *C. obtusifolia* and *C. tora* seeds exhibit a potent larvicidal activity against *A. aegypti* and *C. pipiens pallens*¹⁹⁵. Yang *et al* (2003) studied mosquito larvicidal activity of *C. obtusifolia* seed-derived materials and the biologically active component of seeds was characterized as emodin (Fig. 5) using spectroscopic analysis¹⁹⁶. 1,2-Dihydroxyanthraquinone isolated from seeds strongly

inhibit the growth of *Clostridium perfringens* and *Escherichia coli*. Structure-activity relationship revealed that 1,4-dihydroxyanthraquinone and 1,8-dihydroxyanthraquinone has strong growth-inhibition against *C. perfringens*. In growth-promoting activity, 1,2-, 1,4-, and 1,8-dihydroxyanthraquinones exhibited strong growth-promoting activity to *Bifidobacterium bifidum*¹⁹⁷. Yun-Choi *et al* (1990) found three anthraquinone glycosides, gluco-obtusifolin, gluco-chryso-obtusin and gluco-aurantioobtusin, to be platelet anti-aggregatory constituents of seeds of *C. obtusifolia*¹⁹⁹. Guo *et al* (1998) investigated anthraquinone production in hairy root cultures of *C. obtusifolia* clones transformed with *Agrobacterium rhizogenes* strain 9402. The effects of culture conditions and rare earth element Eu^{3+} on the production of six free anthraquinones have also been investigated. It was found that changes of the elements in the culture medium and addition of rare earth element Eu^{3+} can greatly influence the contents of free anthraquinones in the hairy roots¹⁹¹.

Cassia occidentalis Linn.

Cassia occidentalis Linn. also known as Coffee Senna, Stink Weed, Stinking or Negro Coffee and Kasaundi in India. The leaves and flowers of *C. occidentalis* can be cooked and are edible. It has been reported that the infusion of the leaves is used as an effective treatment for hepatitis²⁰⁴. *C. occidentalis* has long been used as natural medicine in rainforests and other tropical regions for the treatment of inflammation, fever, liver disorders, constipation, worms, fungal infections, ulcers, respiratory infections, snakebite and as a potent abortifacient²⁰⁵. In Senegal, the leaves of *C. occidentalis* are used to protect cowpea seeds, *Vigna unguiculata* Linn. (Walpers) against *Callosobruchus maculatus* (Coleoptera: Bruchidae). Both fresh and dry leaves as well as whole and ground seeds had no contact toxicity on the cowpea beetle²⁰⁶. In contrast, seed oil induced an increase in mortality of *C. maculatus* eggs and first larval instar at the concentration of 10 ml/kg cowpea²⁰⁶. *C. occidentalis* was proved to be toxic to heifers with the more prominent clinical symptoms depressed muscular tone, weakness and slow march that evolutioned in few days until prostration²⁰⁷. The gum derived from seed endosperm can be potentially utilized in a number of industries to replace the conventional gums²⁰⁸. The seeds are bitter and used for winter cough and as a cure of convulsion in

children²⁰⁹. Seeds are commonly used in West Africa to prepare a beverage which serves as a substitute for coffee²⁰⁹. The plant possesses antimutagenic activity against benzo[a]pyrene (BaP) and cyclophosphamide (CP)-induced mutagenicity²¹⁰. It is also found that it modulated hepatic drug metabolizing enzymes. It is suggested that by a similar mechanism, it may be influencing the hematotoxic and immunotoxic responses of cyclophosphamide²¹⁰. *C. occidentalis* is used in Unani medicine for liver ailments and is an important ingredient of several polyherbal formulations marketed for liver diseases. The aqueous-ethanolic extract (50%, v/v) of leaves of the plant produced significant hepatoprotection^{211,212}. This weed has been known to possess antibacterial, antifungal, antidiabetic, anti-inflammatory, anticancerous, antimutagenic and hepatoprotective activity²¹³. Yadav *et al* (2009) mentioned about wide range of chemical compounds including achrosin, aloe-emodin (Fig. 4), emodin (Fig. 5), anthraquinones, anthrones, apigenin, aurantiobtusin, campesterol, cassiollin, chryso-obtusin, chrysophanic acid, chrysarobin, chrysophanol (Fig. 1), chrysoeriol, etc. from this plant²¹⁴. Anthraquinone derivatives reported mainly from leaves, seeds and roots (Table 2) of *C. occidentalis*^{33,37,68,214-217}. Chukwujekwu *et al* (2006) examined the antibacterial activity of the ethanolic root extract and isolated and identified biologically active component as emodin by spectroscopic analysis²¹⁵. Root of the plant contains 4.5% anthraquinone of which 1.9% are free anthraquinones which include 1,8 dihydroxy anthraquinone, emodin, quercetin and a substance similar to rhein (Fig. 2)³⁶.

Cassia podocarpa Guill. & Perr.

It is a commonly grown shrub on old farmland, mainly in forest regions of West Africa and is closely related to recognized "senna", its leaves and fruits are mentioned as purgatives²¹⁷. The decoction of the leaves, roots and flowers is given for the treatment of venereal diseases in women²¹⁷. Fresh leaves are grounded and applied as poultices to the swellings, wounds and used both internally and externally for skin diseases and yaws²¹⁷. For headache, they are rubbed on the forehead and temples and a lotion is made from them for ophthalmia²¹⁷. With proper processing leaves can be substituted for *C. acutifolia* leaves as a vegetative laxative²¹⁷. Like many other members of the genus *C. podocarpa* contains anthraquinone derivatives, responsible for the laxative

properties²¹⁸. The main constituents responsible for above mentioned properties are the anthraquinone glycosides; however the anthraquinone glycosides of *C. podocarpa* leaf and *C. acutifolia* are not likely to be the same²¹⁸. Rai (1988) carried out an analytical investigation of callus tissues from seedlings of *C. podocarpa* grown on Murashige and Skoog agar medium and demonstrated the presence of number of hydroxyl anthraquinone compounds including rhein (Fig. 2) and chrysophanol (Fig. 1)³¹.

Constituents of the leaves and pods of *C. podocarpa* that have been identified include rhein, emodin (Fig. 5), chrysophanol (Table 2) and other combined and free anthraquinones^{30,219-221}. The study of seasonal variations and spectrophotometric determination of anthraquinones in cultivated *C. podocarpa* showed that combined anthraquinones were concentrated in the leaves at peak flowering (2.43%) while the bark had lowest value (0.21%)²²². Anthraquinone glycosides reached peak levels during the months of October to March (dry season), the maximum being recorded during January to March. There was significant drop in glycosidic content during the period April to September (rainy season). There was slight increase in concentration of aglycones during the rainy season which may be due to inter-conversion of some glycosides to the aglycones. However, the free aglycone content is much lower than the glycosides. This is desirable for optimum laxative activity and reduced toxicity²²². The inclusion of *C. podocarpa* in the African Pharmacopoeia will no doubt enhance its commercialization as laxative and for its antimicrobial effect²²².

***Cassia pudibunda* Benth.**

It is a shrubby plant. Messana *et al* (1991) isolated the new naphthopyrone rubrofusarin-6-*O*- β -D-glucopyranoside, quinquangulin-6-*O*- β -D-apiofuranosyl-(1 \rightarrow 6)-*O*- β -D glucopyranoside, quin-quangulin-6-*O*- β -D-glucopyranoside and chrysophanol dimethyl ether by chemical examination of the methanolic extract of the roots of *C. pudibunda*. Moreover known chrysophanol (Fig. 1), physcion (Fig. 3), *cis*-3,3',5,5'-tetrahydroxy-4-methoxystilbene, *trans*-3,3',5,5'-tetrahydroxy-4-methoxystilbene, and cassiaside B were identified (Table 2). The antimicrobial activity of some of these compounds are also reported²²³.

***Cassia pumila* Lam.**

Cassia pumila Lam., popularly known as Sarmal/Nelatagache is a diffuse terrestrial and strout

annual herb that is usually found in shades of trees, crevices of rocks and also in the open gravelly substratum, often hidden amongst grasses²²⁴. It was reported to possess antimicrobial and anti-inflammatory properties²²⁴. Phytochemically, it has been studied only for spasmolytic anthraquinones (Table 2). Out of isolated anthraquinones chrysophanol (Fig. 1) showed papaverine like, non-specific spasmolytic activity on isolated ileum of guinea pig^{30,224}. Shade dried and coarsely powdered plant material when subjected to sequential solvent extraction in Soxhlet extractor successively using petroleum ether, benzene, acetone, chloroform, alcohol and distilled water shown presence of anthraquinones in aqueous extract, while sennosides was detected in all other extracts²²⁴.

***Cassia racemosa* Mill. syn. *Senna racemosa* (Mill.) H.S. Irwin & Barneby**

It is a widely distributed species in Mexico It is used in traditional indigenous medicine against diarrhea and eye infections. Mena-Rejo'na *et al* (2002) reported a new dihydroanthracenone derivative, named racemochryson (Fig. 34) (Table 2) from the hexane extract of the stem bark along with chrysophanol and physcion²²⁵. Methanol extracts of leaves, roots and bark are reported to have good antiprotozoal activity against *Giardia intestinalis* and *Entamoeba histolytica*. Extracts from stem bark and leaves were most active, with an IC₅₀ of 2.10 μ g/ml for *G. intestinalis* and 3.87 μ g/ml for *E. histolytica*²²⁶. Of the previously reported compounds by Mena-Rejo'na *et al* (2002) chrysophanol (Fig. 1), a 1,8-dihydroxy-anthraquinone, was the most active agent against *E. histolytica*, with an IC₅₀ of 6.21 μ g/ml²²⁶.

***Cassia renigera* Wall. ex Benth.**

Cassia renigera Wall. ex Benth. known as Burmese pink cassia is a typical tropical tree that grows to height of up to 10 m, spreads foliage rich branches to all sides. It is known as rich source of anthraquinones and flavonoids (Table 2)³⁰. Ledwani and Singh (2005) reported 1,5,6-trihydroxy-3-methyl-anthraquinone-8-*O*- α -L-glucoside from the bark and its structure elucidated with the help of chemical studies and spectral data²²⁷. They studied dyeing property of crude anthraquinone to develop variety of shades on wool by using different methods²²⁷.

***Cassia reticulata* Willd.**

Cassia reticulata Willd. [syn. *Senna reticulata* (Willd.) H. S. Irwin & Barneby] commonly known as

Golden Lantern tree is a beautiful flowering small tree whose branches spread out in most dignified manner with exquisite dense, pale-green leaves. Extracts of the plant inhibit the growth of some microorganisms like *E. coli*, *A. fecalis*, *S. lutea*, *P. vulgaris*, *S. typhosa*, *P. aeruginosa*, *M. pyogenes* var. *aureus*, *M. pyogenes* var. *albus* and *S. pyogenes* but failed to inhibit the growth of *A. aerogenes*, *S. marcescens*, *B. subtilis* and *H. influenzae*. An aqueous extract was found to be less active²²⁹. Presence of anthraquinones reported from various plant part (Table 2), and therefore anthraquinones are said to be responsible for antimicrobial activity²²⁸⁻²³⁰. Anchel (1949) isolated and identified rhein (Fig. 2) having antibiotic activity²³⁰.

***Cassia siamea* Lam.**

Cassia siamea Lam. is the plant which grows widely in South East Asia and is widely used in Thai traditional medicine. The alcoholic extract of flowers has potent antioxidant activity against free radicals, prevent oxidative damage to major biomolecules and afford significant protection against oxidative damage in the liver²³¹. *C. siamea* has been reported to contain anthraquinones, alkaloids, flavonoids, chromones, and terpenoids. It is used widely in Thailand and the rest of South East Asia as a food plant and in herbal medicine²³². The root and bark of *C. siamea*, a tree which is endemic to Central and East Africa, have been used in folklore medicine to treat stomach complaints and as a mild purgative. It is an important source of anthraquinones (Table 2) which are reported from leaves, stem bark, rootbark and heartwood^{30,36,56,105,233-236}.

Short-term *in vitro* assays for anti-tumor promoters were carried out for several anthraquinones and bianthraquinones, which were isolated from *C. siamea* and derived from cascaroside²³⁵. Koyama *et al* (2001) reported anthraquinone monomers showed higher anti-tumor promoting activity than that of bianthraquinone²³⁵. It was found that cassiamin B (Fig. 36) might be valuable as an anti-tumor-promoting and chemopreventive agent²³⁶.

***Cassia sieberiana* Linn.**

Cassia sieberiana Linn. is a medium-sized tree with compound leaves found in many parts of West Africa. Folkloric evidence supports the use of the species as laxative and purgative in many countries including Nigeria. Presence of various anthraquinone glycosides is responsible for medicinal activity of the

plant; however isolation of anthraquinones is not reported from this species²³⁷. The plant is also found to have antimicrobial activity²³⁸.

***Cassia singueana* Delile**

It is a deciduous shrub or small tree up to 15 m tall, used in northern Nigeria for the treatment of acute malaria attack. Methanol extract of the plant exhibited significant antinociceptive, antipyretic and antiplasmodial activity in all the models²³⁹. Phytochemical screening of the extract revealed the presence of phenols, saponins, tannins and some traces of anthraquinones. The study also paves way for the possible development of it, as a phytodrug against malaria²³⁹. Root bark and roots are reported to have anthraquinone (Table 2) and tetrahydroanthracene derivatives with antimicrobial and antispasmodic activities^{240,241}.

***Cassia sophera* Linn.**

It is a shrub of up to 2 to 3 m in height with subglabrous stems containing leaves up to 25 cm long. The powdered leaves of *C. sophera* along with hot- and cold-water leaf extracts of this plant were tested in laboratory experiments in the UK and in field trials in Tamale, Northern Ghana, using traditional storage containers, to determine their inhibitory and toxic effects against *Sitophilus oryzae* and *Callosobruchus maculatus* infestation of stored rice and cowpea, respectively²⁴². Hot-water extracts might be a more effective technique of applying the plant material on to stored cowpea than using powdered leaves, the currently used application by small-scale farmers²⁴². In contrast, experiments with *S. oryzae* on rice showed that *C. sophera* leaf powder (5% w/w) effectively reduced adult emergence in the laboratory, but this could not be confirmed under field conditions²⁴². The extracts of root, seed and leaf inhibit germination of *Drechslera oryzae* which can be correlated with presence of various anthraquinones (Table 2) reported from this plant^{30,243-245}.

***Cassia spectabilis* DC.**

It is a fast growing Indian tree, the seeds of which contain about 40% of endosperm are potential source of commercial gum²⁴⁶. Anthraquinones (Table 2) are reported mainly from leaves and flower-buds of this plant^{30,247}.

***Cassia tomentosa* Linn. f.**

Cassia tomentosa Linn f. syn. *Senna multiglandulosa* (Jacq.) Irwin & Barneby, native to

tropical America but widely distributed throughout Africa, Asia, Australasia and Central America is a perennial shrub with yellow flowers which are boiled and eaten. Isolation of senglone (9-(phycion-7'-yl) -5,10-dihydroxy-2-methoxy-7-methyl-1,4-anthraquinone) (Fig. 37), emodin (Fig. 5), floribundone 1 (Fig. 22), torosanin-9,10'-quinone and anhydrophlegmacin-9',10'-quinone were reported from *C. tomentosa*⁵⁶.

Cassia tora Linn.

It is a small annual legume shrub that grows as a common weed in Asian countries and cultivated as a traditional medicinal herb for multiple therapies including regulation of blood pressure and blood lipid. Sometimes this species is considered as a synonym of *C. obtusifolia*²⁴⁸. *C. obtusifolia* and *C. tora* are distinct in several important phytochemical characters also. Anthraquinones obtusin, obtusifolin (Fig. 33) are confined only to *C. obtusifolia* while chrysoobtusin to *C. tora*²⁴⁸. Because of naturally occurring acidic soils in south-eastern China, this plant species may possess strategies for tolerance to low pH and aluminum toxicity^{249,250}. *C. tora* is a medicinal plant traditionally used as laxative, for the treatment of leprosy and various skin disorders²⁵¹. *C. tora* is effective against free radical mediated diseases²⁵¹. The dose-dependent spasmogenic effects of the methanolic extract on guinea pig ileum, rabbit jejunum and mice intestinal transit suggested that the use of *C. tora*, traditionally, as a purgative and in the treatment of other ailments is justifiable²⁵². Ononitol monohydrate isolated from leaves is a potent hepatoprotective agent²⁵³. *C. tora* seed is composed of hull (27%), endosperm (32%) and germ (41%)²⁵⁴. Rheological properties of carbamoyl ethyl *C. tora* gum solutions showed non-Newtonian pseudoplastic behaviour regardless of the % N²⁵⁵.

Seeds have physiological functions as an antiseptic, diuretic, diarrhoeal, antioxidant and antimutagen²⁵⁶. Ethanolic extract of seeds and its ether soluble and water soluble fraction decreased serum level of total cholesterol, triglyceride, LDL-cholesterol on the other hand increase serum HDL-cholesterol²⁵⁷. Ethyl acetate fraction of methanol extract from *C. tora* exhibited more antioxidant potency and was found to be more effective in protecting LDL against oxidation in a concentration-dependent manner suggesting that *C. tora* especially ethyl acetate-soluble fraction may

have a preventive effect against atherosclerosis by inhibiting LDL oxidation²⁵⁸. Nicoli *et al* (1997) found that medium dark roasted coffee brews had the highest antioxidant properties due to the development of Maillard reaction products²⁵⁹. Kim *et al* (1994) mentioned that methanol extracts from *C. tora* exhibited strong antioxidant activities on the lipid peroxidation²⁶⁰.

According to Ayurveda, its leaves and seeds are acrid, laxative, antiperiodic, anthelmintic, ophthalmic, liver tonic, cardiogenic and expectorant. The leaves and seeds are useful in leprosy, ringworm, flatulence, colic, dyspepsia, constipation, cough, bronchitis and cardiac disorders²⁶¹. The seeds are reputed in Oriental medicine as vision-improving, antiasthenic, aperient and diuretic agents. *C. tora* have shown to possess various biological and pharmacological activities including antihepatotoxic, radical scavenging, antiallergic, antimutagenic, antifungal and antimicrobial activities²⁶². Anthraquinone derivatives extracted from the seeds have been used traditionally to improve visual acuity²⁶³. Seeds of *C. tora* being major component used for various pharmacological applications worldwide, is extensively studied for presence of anthraquinones (Table 2) however anthraquinones are also reported to be present in all the parts of *C. tora*^{30,248,257,261-277}.

At 1 g/l, the chloroform fraction of *C. tora* seed extract showed strong fungicidal activities against *Botrytis cinerea*, *Erysiphe graminis*, *Phytophthora infestans* and *Rhizoctonia solani*. Emodin (Fig. 5), phycion (Fig. 3) and rhein (Fig. 2) were isolated from the chloroform fraction using chromatographic techniques and showed strong and moderate fungicidal activities against *B. cinerea*, *E. graminis*, *P. infestans* and *R. solani*²⁶⁴. Furthermore, aloe-emodin (Fig. 4) showed strong and moderate fungicidal activities against *B. cinerea* and *R. solani*, respectively, but did not inhibit the growth of *E. graminis*, *P. infestans*, *Puccinia recondita* and *Pyricularia grisea*²⁶⁴.

One component found in seeds of *C. tora*, 2-hydroxy-1,6,7,8-tetramethoxy-3-methylanthraquinone, is known as chrysoobtusin and exhibits a variety of potent biological effects such as suppression of mutagenicity of mycotoxins, antioxidant activity and hypolipidemic activity^{257,263}. Nine anthraquinones, aurantio-obtusin, chryso-obtusin, obtusin, chryso-obtusin-2-O- β -D-glucoside, phycion, emodin, chrysophanol, obtusifolin, and obtusifolin-2-O- β -D-

glucoside, isolated from an EtOAc-soluble extract of the seeds of *C. tora*, which are found to contain inhibitory activity on protein glycation and aldose reductase²⁶².

Roasted seeds of the species have a special flavour and colour, and it is popularly used to make a health drink. The commercial products include both unroasted and roasted samples, and the laxative effect was found to be higher in unroasted samples than in the roasted samples²⁶⁵. Zhang *et al* (1996) reported that some components, e.g., chrysophanol, in *C. tora* were decreased after the roasting process²⁶⁵. Yen and Chung (1999) indicated that the antioxidant activity of methanolic extracts was stronger than that of *C. occidentalis* and they also identified an antioxidative compound as 1,3,8-trihydroxy-6-methyl-9,10-anthracenedione (emodin) from *C. tora*. However, whether the extracts of *C. tora* possess a prooxidant action towards biological molecules remains unclear²⁶⁶. Antigenotoxic properties and the possible mechanisms of water extracts from *C. tora* (WECT) treated with different degrees of roasting (unroasted and roasted at 150 and 250°C) were evaluated by the Ames salmonella/microsome test and the comet assay. Results indicated that WECT, especially unroasted *C. tora* (WEUCT), markedly suppressed the mutagenicity of 2-amino-6-methyldipyrido(1,2-a:3':2'-d)imidazole (Glu-P-1) and 3-amino-1,4-dimethyl-5H-pyrido(4,3-b)indole (Trp-P-1)²⁶⁷. WEUCT showed 84% scavenging effect on oxygen free radicals generated in the activation process of mutagen detected by electron paramagnetic resonance system. The individual anthraquinone content in extracts of *C. tora* was measured by HPLC. Three anthraquinones, chrysophanol, emodin and rhein, have been detected under experimental conditions²⁶⁷. The anthraquinone content decreased with increased roasting temperature. Each of these anthraquinones demonstrated significant antigenotoxicity against Trp-P-1 in the comet assay²⁶⁷. The decrease in antigenotoxic potency of roasted *C. tora* was related to the reduction in their anthraquinones²⁶⁷.

Maity and Dinda (2003) isolated and identified that aloe-emodin, 1,8-dihydroxy-3-(hydroxymethyl)-anthraquinone from the 90% methanolic extract of the dried leaves. The methanolic extract as well as isolated aloe-emodin from leaves was found to contain purgative activity²⁷⁰.

Sui-Ming *et al* (1989) isolated three new anthraquinone glycosides, of which two compounds

exhibited a weak protective effect on primary cultured hepatocytes against carbon tetrachloride toxicity²⁷¹. Cherng *et al* (2008) carried out study of evaluation of the immunostimulatory activities of four anthraquinones, aloe-emodin, emodin, chrysophanol and rhein of *C. tora* on human peripheral blood mononuclear cells (PBMC). The results showed that at non-cytotoxic concentrations, the tested anthraquinones were effective in stimulating the proliferation of resting human PBMC and/or secretion of IFN- γ . However, at the concentration of 10 $\mu\text{g/ml}$ (35 μM), rhein significantly stimulated proliferation of resting human PBMC (stimulation index (SI)=1.53), but inhibited IFN- γ secretion (74.5% of control). The augmentation of lymphocyte proliferation was correlated to the increase in number of CD4⁺T cells, while the elevated secretion of IFN- γ and IL-10 might have been due to the activated CD4⁺T cells²⁷². From the extract of seeds alaternin isolated as one of the active radical scavenging principles of DPPH radical, together with the two naphthopyrone glycosides²⁷⁴. Methanol extract of roasted seeds found to have antimutagenic activity against aflatoxin B₁ (AFB₁). From the methanol extract anthraquinones chrysophanol, aurantiobtusin, and chryso-obtusin were isolated as active principle along with alaternin having significant antimutagenic activity²⁷⁵. It is found that alaternin is a potentially effective and versatile antioxidant and can be used to protect biological systems and it functions against various oxidative stresses²⁷⁶.

Cassia torosa Cav.

Cassia torosa Cav. is reported to contain various anthracene derivatives along with various anthraquinones (Table 2) isolated from different parts of plant²⁷⁸⁻²⁸⁶. Kitanaka and Takido (1990) reported two new dimeric tetrahydroanthracene derivatives, torosaols I and II from the fresh roots of *C. torosa*²⁸⁴. While in further study they reported a new bitetrahydroanthracene derivative, torosaol-III along with physcion, 5,7'-physcionanthrone-physcion, 5,7'-biphyscion, torosanin-9,10-quinone, 5,7-dihydroxy-chromone, naringenin, and chrysoeriol from the flowers of *C. torosa*²⁸⁵. These compounds exhibited cytotoxic activity against KB cells in the tissue culture^{284,285}.

Conclusion

Cassia is a major genus of the Caesalpiniaceae, comprising about 600 species, some of which are used in traditional folk medicines as laxative, purgative,

antimalarial, ulcer healing, anti-diabetic, hepatoprotective, nephroprotective, antitumor and also used in treatment of skin infection and periodic fever throughout tropical and subtropical region. Plants of genus *Cassia* are important source of naturally occurring bioactive compounds anthraquinones. These plants are also reported to have antifungal, antibacterial, antiviral properties along with insecticidal property. Isolation of various anthraquinones from these plants justifies the above mentioned properties. Besides the pharmacological properties anthraquinones are also important as redox mediator in bio-decolorization of dyes and has potential to replace synthesized organic compound used as pesticides, insecticides which associated with carcinogens, toxicants and ecosystem degradation due to its nonbiodegradability and tendency to accumulate in ecosystems. This review highlights the importance of *Cassia* species as an alternative system for biologically active metabolites anthraquinone. The work so far done on *Cassia* species also sets basis for future studies on the effects of anthraquinone containing extracts of the plants which may have important practical implication in grain storage as natural preservative and their potential utilization in development of alternative medicines, novel cancer therapy as well as novel drug to treat viral diseases including polio, AIDS, etc. Antioxidant properties of anthraquinone containing extracts from these plants can be important for protection against number of diseases and reducing oxidation processes in food systems.

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