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Phytochemistry, biological activities and economical uses of the genus *Sterculia* and the related genera: A reveiw

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ABSTRACT

The genus *Sterculia* is represented by 200 species which are widespread mainly in tropical and subtropical regions. Some of the *Sterculia* species are classified under different genera based on special morphological features. These are *Pterygota* Schott & Endl., *Firmiana* Marsili, *Brachychiton* Schott & Endl., *Hildegardia* Schott & Endl., *Pterocymbium* R.Br. and *Scaphium* Schott & Endl. The genus *Sterculia* and the related genera contain mainly flavonoids, whereas terpenoids, phenolic acids, phenylpropanoids, alkaloids, and other types of compounds including sugars, fatty acids, lignans and lignins are of less distribution. The biological activities such as antioxidant, anti-inflammatory, antimicrobial and cytotoxic activities have been reported for several species of the genus. On the other hand, there is confusion on the systematic position and classification of the genus *Sterculia*. However, the wide range of the reported flavonoids in the present review is quite significant and can act as a guide for further studies from the chemosystematic point of view. Also the value of the genus *Sterculia* and its related genera in the traditional medicine and their effective biological activities led to the possibilities of finding new sources of drugs for prospect applications.

1. Introduction

The genus *Sterculia* belongs to the subfamily Sterculioideae of family Malvaceae[1]. It was previously placed in the now obsolete Sterculiaceae, which comprised approximately 200 species distributed mainly in tropical and subtropical regions. Some of the *Sterculia* species are classified under different genera based on distinct morphological features. These are *Pterygota* Schott & Endl., *Firmiana* Marsili, *Brachychiton* Schott & Endl., *Hildegardia* Schott & Endl., *Pterocymbium* R.Br. and *Scaphium* Schott & Endl.[2]. Karaya or Indian gum which is extracted from *Sterculia urens* Roxb. (*S. urens*), was used as a thickener and emulsifier in foods, as a laxative, and as a denture adhesive. Moreover, the root barks of *Firmiana simplex* (L.) W. Wight (*F. simplex*), a Chinese herbal medicine, used in the treatment of numerous disorders such as rheumatism, asthma, fractures and tumors, while its seeds had been used for diarrhea and stomach disorders[3]. Some species from the genus *Sterculia* were used for the production of timber and also cultivated as ornamentals. The genus *Sterculia* contains various classes of compounds including flavonoids and their derivatives, terpenoids mostly as triterpenoids, coumarins, alkaloids and other classes such as phenolic acids, phenyl propanoid, fatty acids, sugars and some steroids[4]. The chemical composition of *Sterculia* and the related genera have received much attention because

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of the distribution of a wide range of flavonoid constituents, which are believed to play a considerable role in plant chemotaxonomy[5]. Moreover, most of them have shown to possess different biological activities[4].

The following chronological literature survey was achieved aiming to provide helpful guidelines for further studies. In this respect, data on isolation and identification of different types of chemical compounds from plants of the genus *Sterculia* and the related genera were gathered and reported in addition to those concerned with the biological activities of these plants.

2. Chemical constituents of the genus *Sterculia* and the related genera

2.1. Flavonoids

A survey of the genus *Sterculia* and the related genera showed a wide range of flavonoid compounds. They occurred mostly as flavone and flavonol glycosides. The flavone glycosides mainly present are as 7-*O*-glucoside and 7-*O*-glucuronide of apigenin, luteolin and chrysoeriol, whereas diosmetin glycosides were not often present. The glycosylation of flavonols at position 3 were common, generally based on quercetin and/or kaempferol. 6- or 8-hydroxyflavones, scutellarein, isoscutellarein, 6-hydroxyluteolin, and hypolaetin were also detected, but that of 6- or 8-hydroxyflavonols were absent. *C*-glycosylflavones were rare; vitexin and apigenin 6,8-di-*C*-β-D-glucoside were reported in *Sterculia colorata* Roxb. (*S. colorata*) and *Sterculia foetida* L. (*S. foetida*), respectively[6,7]. A single isoflavone structure with *C*-glucosyl substituent at position 8 (puerarin) had been also characterized for *S. foetida*[7]. The determined anthocyanins were pelargonidin and cyanidin derivatives. The classes of the flavonoids reported are outlined in Table 1 and classified based on their chemical structures according to Harborne[5].

2.2. Other phenolic constituents

Mono- and dihydroxy-phenolic acids were isolated from the leaves of *S. foetida* and *S. lychnophora* seeds[9,16,18]. Phenoilc

Table 1
Classes of the flavonoids reported from the genus *Sterculia* and the related genera.

Compound		Organ	Species	References
Flavones	Apigenin	Leaves	*S. colorata*	[6]
		Flower	*F. platanifolia*	[8]
		Leaves	*S. foetida*	[9]
		Stem, leaves	*P. alata*	[10]
		Leaves	*B. acerifolius*	[11]
	Apigenin 7-*O*-β-D-glucoside	Leaves	*B. acerifolius*	[11]
	Apigenin 7-*O*-β-D-glucuronide	Leaves	*S. colorata*	[6]
		Leaves	*B. acerifolius*	[11]
	Apigenin 7-*O*-β-D-glucuronide 6"-ethyl ester	Leaves	*S. foetida*	[9]
	Apigenin 7-*O*-(2"-α-rhamnoside)-β-glucuronide	Leaves	*B. acerifolius*	[11]
	6-Hydroxyapigenin (scutellarein)	Leaves	*S. colorata*	[6]
		Leaves	*S. foetida*	[12]
	Scutellarein 6-*O*-β-D-glucuronide	Leaves	*S. foetida*	[12]
	8-Hydroxyapigenin 8-*O*-glucuronide (isoscutellarein 8-*O*-glucuronide)	Leaves	*S. colorata*	[13]
	Isoscutellarein 8-*O*-β-D-glucoside	Leaves	*S. foetida*	[7,9]
	Isoscutellarein 8-*O*-β-D-glucuronide			
	Isoscutellarein 8-*O*-β-D-glucuronide 6"-methyl ester			
	Isoscutellarein 8-*O*-β-D-glucuronide 6"-ethyl ester			
	Isoscutellarein 4'-methyl ether (takakin)			
	Takakin 7-*O*-β-D-glucoside			
	Takakin 8-*O*-β-D-glucoside			
	Takakin 8-*O*-β-D-glucuronide			
	Takakin 8-*O*-β-D-glucuronide 6"-methyl ester			
	Luteolin	Leaves	*S. colorata*	[6]
		Leaves	*B. acerifolius*	[11,14]
		Leaves	*S. foetida*	[9]
	Luteolin 7-*O*-β-D-glucoside	Leaves	*S. foetida*	[9]
	Luteolin 7-*O*-β-D-glucuronide	Leaves	*S. colorata*	[6]
			S. foetida	[9]
			B. acerifolius	[11]
	Luteolin 7-*O*-β-D-glucuronide 6"-methyl ester	Leaves	*S. foetida*	[9]
	Luteolin 7-*O*-β-D-glucuronide 6"-ethyl ester			
	Luteolin 3'-methyl ether (chrysoeriol)	Leaves	*S. villosa*	[15]
		Leaves	*S. foetida*	[9]
	Chrysoeriol 7-*O*-β-D-glucoside	Leaves	*S. villosa*	[15]
	Chrysoeriol 7-*O*-β-D-glucuronide	Leaves	*S. foetida*	[9]

(*continued on next page*)

Table 1 (*continued*)

Compound		Organ	Species	References
	Chrysoeriol 7-*O*-β-D-glucuronide 6"-methyl ester			
	Chrysoeriol 7-*O*-β-D-glucuronide 6"-ethyl ester			
	Luteolin 4'-methyl ether (diosmetin)	Leaves	*S. villosa*	[15]
	Diosmetin 7-*O*-β-D-glucoside			
	6-Hydroxyluteolin	Leaves	*S. colorata*	[6]
	6-Hydroxyluteolin 6-*O*-β-D-glucuronide	Leaves	*S. colorata*	[6]
		Leaves	*S. foetida*	[13]
	8-Hydroxyluteolin 8-*O*-β-D-glucuronide (hypolaetin 8-*O*-β-glucuronide)	Leaves	*S. foetida*	[9,16]
	Hypolaetin 8-*O*-β-D-glucuronide 6"-methyl ester			
	Hypolaetin 8-*O*-β-D-glucuronide 6"-ethyl ester			
	Hypolaetin 3'-methyl ether 8-*O*-β-D-glucuronide 6"-methyl ester			
	Hypolaetin 4'-methyl ether 8-*O*-β-D-glucuronide 2"-sulfate			
	Hypolaetin 4'-methyl ether 3'-*O*-β-D-glucoside			
	5,7,8,3'-Tetrahydroxy 4'-methoxy flavone	Leaves	*S. foetida*	[7]
	5,7,8-Trihydroxy 3',4' dimethoxy flavone			
Flavonols	Kaempferol	Leaves	*F. simplex*	[15]
		Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
		Leaves	*B. acerifolius*	[11,14]
	Kaempferol 3-*O*-β-D-glucoside	Stem bark	*S. diversifolia*	[17]
		Seeds	*S. lychnophora*	[18]
		Fruit	*S. scaphigerum*	[19]
	Kaempferol 3-*O*-β-D-rutinoside	Leaves	*F. simplex*	[15]
		Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	
		Seeds	*S. lychnophora*	[18]
		Fruit	*S. scaphigerum*	[19]
	Kaempferol 3-*O*-(2”,6”-dirhamnosyl)-β-glucoside [K 3-*O*-(2”-rhamnosylrutinoside)]	Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
	Kaempferol 3-*O*-(2",6"-dirhamnosyl)-β-galactoside [K 3-*O*-(2"-rhamnosylrobinoside)]	Leaves	*B. rupestris*	[17]
	Quercetin	Leaves	*S. pallens*	[20]
		Leaves	*F. simplex*	[15]
		Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
		Leaves	*B. australis*	[21]
		Leaves	*B. acerifolius*	[11,14]
		Leaves	*B. discolor*	[22]
		Leaves	*S. foetida*	[9]
	Quercetin 3-*O*-arabinoside	Stem bark	*S. diversifolia*	[17]
	Quercetin monorhamnoside	Roots	*S. foetida*	[23]
	Quercetin 3-*O*-rhamnoside (quercitrin)	Stem bark	*F. platanifolia*	[24]
		Stem	*F. simplex*	[25,26]
		Leaves	*B. discolor*	[22]
	Quercetin 3-O-β-D-glucoside	Leaves	*S. pallens*	[20]
		Leaves	*B. australis*	[21]
		Leaves	*S. foetida*	[7]
	Quercetin 3-*O*-galactoside (hyperoside)	Leaves	*F. simplex*	[15]
		Leaves	*B. acerifolius*	[11,17]
	Quercetin 3-*O*-(6"-α-rhamnosyl)-β-glucoside (rutin)	Leaves	*F. simplex*	[27]
		Leaves	*B. australis*	[21]
		Leaves	*B. acerifolius*	[11,14]
	Quercetin 3-*O*-(2"-α-rhamnosyl)-β-D-glucoside	Leaves	*F. simplex*	[15]
	Quercetin 3-*O*-diglucoside	Leaves	*S. pallens*	[20]
	Quercetin 7-methyl ether (rhamnetin)	Leaves	*B. discolor*	[22]
	Quercetin 3’-methyl ether (isorhamnetin)	Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
		Leaves	*B. acerifolius*	[14]
	Isorhamnetin 3-*O*-β-D-rutinoside	Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
		Leaves	*B. australis*	[21]
		Seeds	*S. lychnophora*	[18]
		Fruit	*S. scaphigerum*	[19]

(*continued on next page*)

Table 1 (*continued*)

Compound		Organ	Species	References
	Quercetin 3'-methyl ether (isorhamnetin)	Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
		Leaves	*B. acerifolius*	[14]
	Isorhamnetin 3-*O*-β-D-rutinoside	Leaves	*B. rupestris*	[17]
		Stem bark	*S. diversifolia*	[17]
		Leaves	*B. australis*	[21]
		Seeds	*S. lychnophora*	[18]
		Fruit	*S. scaphigerum*	[19]
	Isorhamnetin 3-*O* -(2",6"-dirhamnosyl)-β-D-galactoside	Leaves	*B. rupestris*	[17]
	Quercetin 4'-methyl ether-3-*O*-rhamnoside (tamarixetin 3-*O*-rhamnoside)	Stem bark	*F. simplex*	[25,26]
	Quercetin 3,7,3',4'-tetramethyl ether (retusin)	Stem bark	*S. foetida*	[28]
	Quercetin 5,7,3',4'-tetramethyl ether	Stem bark	*S. foetida*	[28]
Flavans	5,7-Dihydroxy-2-(4-hydroxyphenyl)-6,8-dimethylchroman-4-one (farrerol)	Roots	*H. barteri*	[29]
C-Glycosyl flavonoids	Apigenin 8-*C*-β-glucoside (vitexin)	Leaves	*S. colorata*	[6]
	Apigenin 6,8-di-*C*-β-glucoside	Leaves	*S. foetida*	[7]
Isoflavones	8-*C*-glucoside-7,4'-dihydroxyisoflavone (Puerarin)	Leaves	*S. foetida*	[7]
Isoflavans	(3 R)-6, 2'-dihydroxy-7-methoxy-4', 5'-methylenedioxyisoflavan (hildegardiol)	Roots	*H. barteri*	[29]
	2-Hydroxymaackiain	Roots	*H. barteri*	[29]
Anthocyanins	Pelargonidin	Follicles	*S. parviflora*	[30]
		Follicles	*S. kunstleri*	[30]
	Pelargonidin 3-*O*-arabinoside	Follicles	*S. parviflora*	[30]
	Pelargonidin 3-*O*-galactoside	Follicles	*S. parviflora*	[30]
			S. kunstleri	[30]
	Pelargonidin 3-*O*-glucoside	Follicles	*S. parviflora*	[30]
		Flower	*B. acerifolius*	[11]
	Cyanidin 3-*O*-arabinoside	Follicles	*S. parviflora*	[30]
	Cyanidin 3-*O*-galactoside	Follicles	*S. parviflora*	[30]
	Cyanidin 3-*O*-glucoside	Flower, Leaves	*S. foetida*	[30]
		Leaves	*F. platanifolia*	[31]
		Leaves	*S. foetida*	[13]
	Cyanidin 3-*O*-rutinoside	Flower	*B. acerifolius*	[11]
	Leucoanthocyanidin-3-*O*-α-L-rhamnopyranoside	Roots	*S. foetida*	[23]
	Procyanidin-β-D-glucuronide	Leaves	*S. foetida*	[13]

F. platanifolia: *Firmiana platanifolia* Schott et Endl.; *P. alata*: *Pterygota alata* (Roxb.) R. Br.; *B. acerifolius*: *Brachychiton acerifolius* (A.Cunn.ex G.Don) Macarthur; *S. villosa*: *Sterculia villosa* Roxb.; *B. rupestris*: *Brachychiton rupestris* (Lindl.) K. Schum; *S. diversifolia*: *Sterculia diversifolia* G. Don; *S. lychnophora*: *Sterculia lychnophora* Hance; *S. scaphigerum*: *Scaphium scaphigerum* (G. Don) Guib. & Planch.; *S. pallens*: *Sterculia pallens* Wall. Ex Hochr.; *B. australis*: *Brachychiton australis* (Schott & Endl.) A. Terrac; *B. discolor*: *Brachychiton discolor* F.j. Muell.; *H. barteri*: *Hildegardia barteri* (Mast.) Kosterm.; *S. parviflora*: *Sterculia parviflora* Roxb; *S. kunstleri*: *Sterculia kunstleri* King.

aldehydes were rare. The genus *Sterculia* comprises two major classes of phenylpropanoids: cinnamic acids and coumarins. Cinnamic acid was isolated from *P. alata*, while the common cinnamic acid derivatives, *p*-coumaric and ferulic acids were reported in *S. foetida*[9,10,16]. Coumarin compounds are mostly represented by scopoletin, which was isolated from the leaves of *B. australis* and *Firmiana hainanensis* Kosterm. (*F. hainanensis*), *F. simplex* stem and *S. urens* roots[21,23,25,32]. Scopolin and other coumarin derivatives were reported in *S. foetida*[9]. Lignans and lignins were reported in *F. simplex* leaves and the stems of *P. alata*, while dioxane lignin was obtained from the leaves of *Pterygota macrocarpa* K. Schum. (*P. macrocarpa*) as shown in Table 2[25,34].

2.3. Terpenoids and steroids

Limited terpenoids have been reported in the genus *Sterculia* and all are represented by triterpenes. Three new ursane triterpene saponins were recently isolated from the stems of *F. simplex*: 28-*O*-[β-D-glucopyranosyl-(1→6)-β-D-glucopyranosyl]-2α,3α,19α-trihydroxy-12-en-28-ursolic acid, 28-*O*-[β-D-glucopyranosyl-(1→6)-β-D-glucopyranosyl]-2α,3α,19α,23-tetrahydroxy-12-en-28-ursolic acid and 28-*O*-[β-D-glucopyranosyl-(1→6)-β-D-glucopyranosyl]-2α,3β,19α-trihydroxyurs-12-ene-24,28-dioic acid[34]. Steroids were also found in some species of the same genus; β-sitosterol and stigmasterol were isolated from certain parts of some species, while β-sitosterol-3-*O*-β-D-glucopyranoside was reported in *S. foetida* and *Sterculia striata* St. Hil. et Naud (*S. striata*)[28,35]. Table 3 describes the terpenoids and steroids reported in the genus *Sterculia* and related genera.

2.4. Miscellaneous compounds

Species of the genus *Sterculia* were also reported to contain several compounds from other classes, as shown in Table 4. Two

alkaloids (sterculinine I and II) were isolated from the seeds of *S. lychnophora* together with two non-alkaloide nitrogenous bases (uracil and adenosine)[19]. The common purine alkaloid (caffeine) was identified from *B. discolor*[22]. Several fatty acids (linoleic, oleic, malvalic, palmitic and sterculic acids) were reported from *S. foetida* and most of *Brachychiton* species, while dihydromalvalic and dihydrosterculic acids were from *Pterygota perrieri* Hochr., *B. gregorii* and *Sterculia tavia* H. Bn[49-52].

3. Biological activities of the genus *Sterculia*

Several biological activities have been reported in different extracts of certain parts of some species of the genus *Sterculia* and related genera. Collectively, Table 5 shows the reported activities *viz*: antimicrobial, antioxidant, anticancer, anti-inflammatory and others.

4. Economical uses

Plants from the genus *Sterculia* have some economical uses in several countries. Almost leaves and gum were reported to exhibit a broad range of economical properties (Table 6).

Table 2
Phenolics from the genus *Sterculia* and the related genera.

Compounds		Organ	Species	References
Phenolic acids and aldehydes	*p*-Hydroxy-benzoic acid	Leaves	*S. foetida*	[9]
	2,4-Dihydroxy-benzoic acid	Seeds	*S. lychnophora*	[19]
	3,4- Dihydroxy-benzoic acid	Leaves	*S. foetida*	[9]
	4-Hydoxy-3,5-dimethoxy-benzoic acid 4-*O*-β-D-glucopyranosyloxy	Leaves	*F. hainanensis*	[32]
		Leaves	*S. foetida*	[16]
	4-Hydoxy-3,5-dimethoxyl benzaldehyde	Leaves	*F. hainanensis*	[32]
Phenyl propanoids	Cinnamic acid	Stem, leaves	*P. alata*	[10]
	p-Methoxy-cinnamic acid	Leaves	*P. alata*	[10]
	1,6-*O*-Dicinnamoyl-glucose	Leaves	*P. alata*	[10]
	p-Coumaric acid	Leaves	*S. foetida*	[9,16]
	cis-*p*-Coumaric acid β-glucoside	Leaves	*S. foetida*	[7]
	trans-Ferulic acid β-glucoside	Leaves	*S. foetida*	[9]
	1,6-Diferuloyl glucose	Leaves	*S. foetida*	[7]
	1-*O*-*p*-Coumaroyl 6-*O*-cinnamoyl-β-D-galactoside	Leaves	*P. alata*	[10]
Coumarins	Scopoletin (7-hydroxy-6-methoxy-chromen-2-one)	Roots	*S. urens*	[23]
		Leaves	*B. australis*	[21]
		Stem	*F. simplex*	[25]
		Leaves	*F. hainanensis*	[32]
	Scopolin (scopoletin 7-*O*-β-D-glucoside)	Leaves	*S. foetida*	[9,16]
	5,7-Dihydroxy-6-methoxy-7-*O*-β-D-glucosyl coumarin			
	Fraxetin 7-*O*-β-D-glucoside (7,8-dihydroxy-6-methoxychromen-2-one 7-*O*-β-D-glucoside)			
	Isofraxidin 7-*O*-β-D-glucoside (7-hydroxy-6,8-dimethoxychromen-2-one 7-*O*-β-D-glucoside)			
	Aquillochin	Stem	*F. simplex*	[25]
Lignans	Thespesone	Leaves	*P. alata*	[10]
	Epieudesmin	Leaves	*P. alata*	[10]
	Diayangambin	Leaves	*P. alata*	[10]
	Simplidin	Stem	*F. simplex*	[25]
	Syringaresinol	Stem	*F. simplex*	[25]
	Nitidanin	Stem	*F. simplex*	[25]
Lignins	Dioxane lignin	Leaves	*P. macrocarpa*	[33]

Table 3
Terpenoids and steroids from the genus *Sterculia* and related genera.

Compounds		Organ	Species	References
Triterpenes	Betulinic acid	Stem bark	*S. foetida*	[28]
		Leaves	*S. striata*	[35]
	Lanosterol, β-amyrin acetate	Leaves	*B. australis*	[21]
		Leaves	*B. discolor*	[22]
	β-Amyrin	Leaves	*F. simplex*	[36]
		Leaves	*B. discolor*	[22]
	Lupenone	Stem bark	*S. foetida*	[28]
		Leaves	*S. striata*	[35]
	Lupeol	Stem bark	*S. foetida*	[28]
		Leaves	*B. australis*	[21]
		Leaves	*B. discolor*	[22]
	3-*O*-β-Acyl-lupeol	Leaves	*S. striata*	[35]
	Oleanolic acid	Leaves	*B. australis*	[21]
		Leaves	*B. discolor*	[22]
		Stem, leaves	*P. alata*	[10]
	28-*O*-[β-D-Glucopyranosyl-(1→6)-β-D-glucopyranosyl]-2α,3α,19α-trihydroxy-12-en-28-ursolic acid	Stem	*F. simplex*	[34]
	28-*O*-[β-D-Glucopyranosyl-(1→6)-β-D-glucopyranosyl]-2α,3α,19α,23-tetrahydroxy-12-en-28-ursolic acid			
	Kajiichigoside F1			
	Nigaichigoside F2			
	Euscaphic acid			
	Myrianthic acid			
	Kakisaponin A			
	Trachelosperoside A			
	Pormolic acid-28-*O*-β-D-gluco-pyranosyl ester			
	23-hydroxyursolic acid			
	2α,3α,24-trihydroxyurs-12-en-28-oic acid-28-*O*-β-D-glucopyranosyl ester			
	Arjunolic acid			
	2α,3α,23-trihydroxyursa-12,20(30) dien-28-oic acid			
Steroids	β-Sitosterol	Young leaves	*F. simplex*	[36]
		Leaves, stem bark, heart wood	*S. foetida*	[9,28]
		Flower	*F. platanifolia*	[8]
		Leaves	*B. australis*	[21]
		Stem bark	*S. striata*	[35]
	β-Sitosterol-3-*O*-β-D-glucoside	Leaves	*S. foetida*	[28]
		Stem bark	*S. striata*	[35]
	Stigmasterol	Leaves	*B. australis*	[21]
		Stem bark	*S. striata*	[35]
		Stem, leaves	*P. alata*	[10]
	Cholesterol	Leaves	*B. australis*	[21]
	Daucosterol	Leaves	*S. foetida*	[9]
		Seeds	*S. lychnophora*	[18]
	5α,6β-Dihydroxy daucosterol	Leaves	*S. foetida*	[9]
	Taraxerol	Leaves	*S. foetida*	[28]
	Taraxeryl acetate	Stem	*P. alata*	[10]
	Friedelin	Leaves	*P. alata*	[10]
	Epifriedelanol	Leaves	*P. alata*	[10]

5. Conclusion

The chronological literature survey confirmed what was originally believed, that the major production of genus *Sterculia* and related genera is indeed flavonoid metabolites. These results also confirm that flavoniod patterns play a significant role in plant chemotaxonomy. They include flavones, flavone *C*-glycosides, flavonols, flavans, isoflavones, isoflavans and anthocyanins. Other phenolic constituents such as, phenolic acids and aldehydes, phenyl propanoids, coumarins, lignans and lignins were identified with a much less significance than flavonoids. On the

Table 4

Miscellaneous compounds from the genus *Sterculia* and the related genera.

Compounds		Organ	Species	References
Alkaloids	Caffeine	Seeds	*B. discolor*	[22]
	Purine	Seeds	*B. discolor*	[22]
	Sterculinine I	Seeds	*S. lychnophora*	[18]
	Sterculinine II	Seeds	*S. lychnophora*	[18]
Non-alkaloid nitrogenous bases	Adenosine	Seeds	*S. lychnophora*	[18]
	Choline	Leaves	*F. platanifolia*	[37]
	Betaine	Leaves	*F. platanifolia*	[37]
	Uracil	Seeds	*S. lychnophora*	[18]
Alcohols	*n*-Octacosanol	Leaves	*S. foetida*	[28]
	Hexacosanol	Heart-wood	*S. foetida*	[28]
	Docosanol	Leaves	*S. guttata*	[38]
Carboxylic acids	Ascorbic acid	Seeds	*S. foetida*	[39]
		Leaves	*S. urens*	[39]
	Succinic acid	Seeds	*S. lychnophora*	[18]
Amides	Soya-cerebroside II	Seeds	*S. lychnophora*	[18]
Triglycerides	Triolein	Seeds	*B. luridum*	[40]
	2-oleodipalmitin			
	2-oleo-3-stearopalmitin			
Sugars	Arabinose	Leaves	*B. diversifolium*	[41]
		Stem bark	*F. platanifolia*	[42]
		Leaves	*F. platanifolia*	[42]
		Leaves	*B. australis*	[21]
	Xylose	Leaves	*B. diversifolium*	[41]
		Leaves	*B. australis*	[21]
		Tree	*S. urens*	[43]
	Rhamnose	Leaves	*B. diversifolium*	[41]
		Seeds	*S. lychnophora*	[44]
		Leaves	*B. australis*	[21]
		Tree	*S. urens*	[43]
		Tree	*S. striata*	[43]
	Galactose	Leaves	*B. diversifolium*	[41]
		Stem bark	*F. platanifolia*	[42]
		Leaves	*F. platanifolia*	[44]
		Leaves	*B. australis*	[21]
		Tree	*S. striata*	[43]
		Tree	*S. urens*	[43]
	Glucuronic acid	Stem bark	*F. platanifolia*	[42]
		Leaves	*S. foetida*	[6]
		Tree	*S. striata*	[43]
		Tree	*S. urens*	[43]
	Galacturonic acid	Leaves	*B. australis*	[21]
		Tree	*S. striata*	[43]
		Tree	*S. urens*	[43]
	Sucrose	Leaves	*F. platanifolia*	[45]
		Seeds	*S. lychnophora*	[18]
	n-butyl-α-D-mannopyranoside	Seeds	*S. lychnophora*	[18]
Fatty acids	Oleic, linoleic, malvalic and sterculic	Seeds	*B. acuminatus*, *B. gregorii*, *B. luridum*, *Brachychiton* cv.'*Hybridum*', *B. populneus*, *S. foetida*, *B. diversifolius*, *B. rupestris*, *B. acerifolius*, *B. discolor* and *B. australis*	[38,39]
	Palmitic	Seeds	*B. australis*	[21]
		Seeds	*B. luridum*	[46]
		Seeds	*S. striata*	[47]
		Stem bark, leaves	*B. diversifolius*	[37]
	Dihydromalvalic and dihydrosterculic	Seeds	*P. perrieri*, *B. gregorii* and *S. tavia*	[37-39]
	Myristic	Stem bark, leaves	*B. diversifolius*	[37]
	Cyclopropenoid fatty acids	Fruits	*S. striata*	[48]

S. guttata: *Sterculia guttata* Roxb.; *B. luridum*: *Brachychiton luridum* C. Moore; *B. diversifolium*: *Brachychiton diversifolium* R. Br.; *B. acuminatus*: *Brachychiton acuminatus* Guymer; *B. gregorii*: *Brachychiton gregorii* F. Muell.; *B. diversifolius*: *B. diversifolius*; *P. perrieri*: *Pterygota perrieri* Hochr.; *S. tavia*: *Sterculia tavia* H. Bn.

Table 5

The biological activities screened for the genus *Sterculia* and related genera.

Biological activity/mode of action		Organ	Species	References
Antimicrobial activity	Cytomegalovirus and encephalomyocaditis viral infections	Leaves	*S. urens*	[53]
	Mild antiprotozoal effect		*B. populneus*	[54]
	Active against larvae of *Aedes aegypti* and *Culex quinquefasciatus*	Seeds	*S. guttata*	[42]
	Bactericidal against *S. aureus*	Stem bark, leaves	*P. milbraedii*	[55]
	Strong anti-schistosomal activity (LC_{50}: 11.6 μg/mL)	Leaves, branches	*B. rupestris*	[56]
	Potent antifungal plant	Leaves	*S. africana*	[57]
	Antibacterial activity inhibiting the growth of *Staphylococcus aureus* and *Escherichia coli* and *Entamoeba histolytica* parasite	Leaves	*S. foetida*	[58]
	Active against *Escherichia coli*, *S. aureus*, *Pseudomonas aeruginosa* and *Bacillus subtilis* but less active against *Candida albicans*	Leaves stem bark	*P. macrocarpa*	[59]
	Moderate antibacterial activity	Wood branches	*B. diversifolius*	[60]
Antioxidant activity	Enhanced the antioxidant activity of components	Stem, leaves, fruit	*F. simplex*	[61]
	Moderate activity	Wood branches	*B. diversifolius*	[60]
		Stem bark	*S. scaphigerum*	[19]
	Efficient reducing power as well as free radical scavenging property	Stem bark	*P. alata*	[62]
Anticancer activity	Chinese pharmaceutical formulation for malignant tumours	Leaves	*S. lychnophora*	[63]
	High cytotoxic effect in almost all tests	Leaves	*S. africana*	[57]
	The ethanol extracts had moderate activity against BGC-823, Bel-7402 and HCT-8 cell lines	Leaves	*S. foetida*	[7,9]
Anti-inflammatory activity		Leaves	*S. lychnophora*	[64-66]
		Leaves	*S. foetida*	[9,67]
		Leaves, stem bark	*P. macrocarpa*	[59]
Laryngopharyngitis diseases and tonsillitis		Leaves	*S. scaphigera*	[68,69]
		Leaves	*S. lychnophora*	[70-72]
Cardiovascular diseases	Induced thrombus fomation	Seeds	*F. simplex*	[73]
	Treating hypertension	Leaves	*F. simplex*	[74,75]
	For treating stroke and hemiplegia	Leaves	*S. lychnophora*	[76]
Digestive system disorders	Stomachache, pains and disorders of digestion	Soaked leaves	*P. macrocarpa*	[59]
	Antiflatulent	Leaves	*S. lychnophora*	[77,78]
Urinary tract disorders	Gonorrhea and other urinary tract infections	Leaves decoction	*P. macrocarpa*	[59]
	Uroschesis	Leaves	*S. lychnophora*	[79]
Skin problems treatment	Anti-aging cosmetics	Leaves	*S. lychnophora*	[80,81]
	Moisturizing agent	Leaves	*S. lychnophora*	[82]
		Leaves	*F. platanifolia*	[83]
	Tyrosinase inhibitors in skin lightening cosmetics	Leaves	*S. foetida*	[84]
	Alopecia and anti-dandruff agent	Leaves	*S. foetida*	[85]
	Hair growth stimulation	Leaves	*F. simplex*	[86]
	Treatment of UV-induced skin disorders, such as wrinkles, skin thickenings and skin tumors	Leaves	*F. simplex*	[87]

(*continued on next page*)

Table 5 (*continued*)

Biological activity/mode of action		Organ	Species	References
	Atopic dermatitis	Leaves	*F. simplex*	[88]
	Burn injury	Leaves	*F. simplex*	[89]
	Vitiligo	Leaves	*F. simplex*	[90]
	Hypoglycemic effect	Leaves	*B. rupestris*	[17]
			S. urens	[91]
			B. australis	[21]
			S. lychnophora	[92]
			S. foetida	[93]
	Anti-obesity drugs	Leaves	*F. simplex*	[94]
		Leaves	*S. lychnophora*	[95]
Nutrient agent	Vitamin C (52 mg/100 g) and Vitamin A (396mg/100 g)	Plant gum	*Sterculia* spp.	[96]
Oral and throat diseases	Throat moisturizing agents	Seeds	*S. scaphigera*	[97]
	Promoting salivation	Leaves	*S. lychnophora*	[98]
	Relieving sore throat	Leaves	*S. lychnophora*	[99]
	Bronchitis	Roots	*F. simplex*	[100]
		Leaves	*S. lychnophora*	[101]
Central nervous system	Treating narcotic drug abuse	Leaves	*S. lychnophora*	[102]
	Depressant activity on CNS with a sleeping effect	Leaves	*S. foetida*	[7,16]
Nasosinusitis		Leaves	*S. lychnophora*	[103]
Anti-hyperlipidimic		Leaves	*S. foetida*	[93]
Hepato-protective agent	Lowered serum SGOT, SGPT and ALP levels	Leaves	*S. foetida*	[93]
	To attenuate the development of alcoholic liver disease	Stem bark	*F. simplex*	[27]
Miscellaneous diseases treatment	Acute and chronic faucitis and symptoms of hoarseness and aphonia	Leaves	*S. lychnophora*	[104]
	Obstinate halitosis	Seeds	*S. scaphigera*	[105]
	Beriberi	Leaves	*F. simplex*	[106]
	Bone fracture, trauma-induced paralysis and osteonecrosis	Roots, stem bark	*F. simplex*	[107]
Health care	Multiple health care functions	Leaves	*S. lychnophora*	[76,108]
	Blood circulation promoting, blood stasis removing, anti-aging and immunity enhancing effects	Leaves	*S. lychnophora*	[99]
	Clearing lung, relieving cough and improving immunity	Leaves	*S. lychnophora*	[109]
	Improving intelligence, eye sight, blood circulation, coronary circulation, nourish liver, lung and throat, body fluid production, regulating nerve, nourishing liver, dispelling blood stasis. Treating malaria, constipation, arteriosclerosis, obesity, hypertension, hyperlipemia, hyperglycemia, thrombosis, intracerebral hemorrhage and relieving itching	Leaves and seeds	*S. lychnophora*	[48,66,110]
	Treating diarrhea, arthritis, edema, gout and whitlow. Anaesthetic effect	Leaves, stem bark and seeds	*S. tragacantha*	[111]

P. milbraedii: *Pterygota milbraedii* Engl; *S. africana*: *Sterculia africana* (Lour.) Fiori; *S. scaphigera*: *Sterculia scaphigera* Wall; *S. tragacantha*: *Sterculia tragacantha* Lindl.

other hand, other metabolites were also reported; *e.g.* terpenoids, steroids, alkaloids as well as sugars and fatty acids. The stems, barks, leaves, fruits and roots of the *Sterculia* species have various and numerous traditional and medicinal uses in various countries to treat a broad range of ailments, digestive diseases, diabetes, respiratory-related diseases and skin diseases. In addition, various biological activities such as antimicrobial, anti-inflammatory, antioxidant and anticancer have been reported for *Sterculia* species. The authors recommend further investigations to study infrageneric relationships within *Sterculia* species to better understand their classification problems.

Table 6

Economical uses of the genus *Sterculia* and its related genra.

Uses		Organ	Species	References
Cigarette manufacturing	Flavoring agent and as an additive sprayed on tobacco	Leaves	*S. scaphigera*	[112]
	A leafy plant cigarette which meet the requirements of smokers without harm to health	Leaves	*F. simplex*	[113]
	Non-tobacco cigarette	Leaves	*S. lychnophora*	[114]
Wastewater treatment	Preparation of activated carbon for removing Cu (II) from aqueous solutions	Fruit shell	*S. foetida*	[115]
	Sorption and desorption properties for Pb and Cd	Seeds	*S. lychnophora*	[116]
	Preparation of activated carbons to adsorb phenol from wastewater	Fruit shell	*P. alata*	[117]
	Lead and copper were adsorbed on plant sawdust in aqueous acid solutions	Leaves	*P. macrocarpa*	[118]
	Mineralized into an enhanced adsorbent for Pb (II) and Hg (II) removal from polluted wastewaters	Leaves	*F. simplex*	[119]
	Efficiently remove Cd (II) from aqueous solutions			[74]
Miscellaneous	Production of cement-bonded wood floor boards	Heart wood	*P. alata*	[120]
	Raw material for making pulp and paper	Leaves	*S. villosa*	[121]
	As a base for cosmetics, bath preparations and detergent formulations	Leaves	*F. simplex*	[82]
	A wood vinegar composition used as: pest controlling agent, bactericidal agent, detergent, environment improver, plant nutrient, soil conditioner and odour remover			[122]
	Nutritious effervescent tablets	Leaves	*S. africana*	[123]
	Effective polymer for the design of different ocular dosage forms: solution or drops, nano-particles, nano-suspensions or suspensions, micro or nano-emulsions, lotions, gels, hydro-gels, in situ forming gels, ointments, inserted films and minitablets	Plant gum	*S. foetida*	[124]

Conflict of interest statement

We declare that we have no conflict of interest.

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