REVIEW

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Furanoflavonoids: an overview

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The review covers the phytochemistry and pharmacology of furanoflavonoids describing 291 compounds and containing 228 references.

1 Introduction

The aim of the review is to survey the chemical and biological literature related to the furanoflavonoid class of compounds. To date, no comprehensive review has been undertaken. Although the distribution of furanoflavonoids among plants is relatively sparse, they nevertheless form a large and very distinctive subclass of the flavonoid family with a wide variety of structural variations. In the present review, an overview of the angular and linear furanoflavonoids, dihydrofurano flavonoids, bis-furanoflavonoids, flavonoid ketohexofuranosides and furano-biflavonoids is presented. This review has arisen from our work on the medicinal plant *Pongamia pinnata*.[1,2]

Rakesh Maurya was born in Bhadohi, India in 1954. He studied for his MSc in organic chemistry (1978) and received his PhD degree (1984) in the workgroup of Professor A. B. Ray at the Banaras Hindu University. In 1984 he was appointed as a research assistant with Professor Sukh Dev, Malti-Chem Research Centre. In 1985 he received a Minna-James-Heinemann Stiftung, West Germany, fellowship to carry out research at the Weizmann Institute of Science, Israel, where he worked on the synthesis of natural products with Professor E. Ghera. In 1987, he moved with Professor Alfred Hassner to the Bar-Ilan University, Israel, where he applied an intramolecular oxime olefin cycloaddition route to the synthesis of fused five-membered heterocyclic rings. Following postdoctoral appointments with Professor C. J. M. Stirling (University of Wales, Bangor, UK) and Professor Stanley M. Roberts (University of Exeter, UK), in 1991 he was appointed as Assistant Director, Regional Research Laboratory, Jammu, India, where he worked on the chemistry of natural products of biological importance. In 1994 he went to Professor Tomas Hudlicky, Virginia Polytechnic Institute and State University, USA, for one year on special leave, where he conducted the asymmetric total synthesis of (+)-7-deoxypancratistatin, L-chiro-inositol conjugates and oligomers. In 2001 he obtained a transfer to the Central Drug Research Institute, Lucknow, where he was promoted to Senior Assistant Director. His main research interests are focused on the isolation, structure determination, chemical transformation and synthesis of natural products with biological properties.

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Prem Prakash Yadav was born in 1978 in Azamgarh, India. He obtained his MSc (organic chemistry) from the University of Allahabad in 2001 and joined the research group of Dr R. Maurya at CDRI, India, as a research scholar. Presently, he is working as a senior research fellow of CSIR at the medicinal and process chemistry division, CDRI, India. Working on the phytochemical evaluation of medicinal plants, chemical transformation and syntheses of bio-active natural products, he has submitted his thesis for the award of a PhD degree in chemistry. Presently, he is involved in the syntheses of analogues of active natural products for biological studies.

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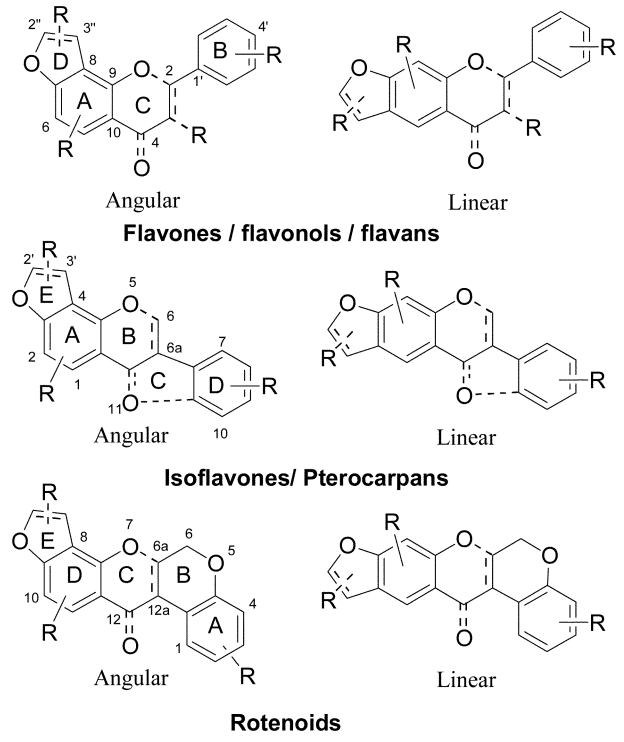
Furanoflavonoids are a major family of secondary metabolites that occur mainly in leguminous plants with a few examples of other families. They are characterized with a linear or angular anellated furan ring attached to the A-ring of various flavonoids. This broad class of flavonoids can be represented schematically as follows:



2 Furanoflavonoids

2.1 Flavones

Flavones bearing a furan ring anellated at C-7, 8 (angular) or C-6, 7 (linear) of ring-A belong to this category. One of the compounds, **29**, has an anellation pattern that is different from other compounds *i.e.* it has the furan ring anellated to the C-5, 6 position (Table 1).[3] Examination of the literature revealed that lanceolatin (**1**) has some quinone reductase activity (CD μM 22.9, CI >3.3).[4] The antifungal activities of lanceolatin (**1**), pongaglabol methyl ether (**8**) and pinnatin (**24**) were reported with compound **8** being the most active antifungal agent amongst the compounds screened and SAR studies revealed that methoxyl substitution at C-5 was crucial for fungitoxic activity for furanoflavonoids.[5] Lanceolatin (**1**) along with karanjin have been screened for cytotoxicity, anti-herpes simplex virus and anti-inflammatory activities but were found to be inactive.[6] Ovalifolin (**20**), pongol methyl ether (**13**) and 3, 4-dimethoxyfuranoflavone (**19**) have been screened for their anti-herpes simplex virus (HSV-1 and HSV-2) activity and were found to possess moderate activity. Sanaganone (**21**) had a unique cyclization producing furan and chromene substitutions in ring-A.[7] Glycosides of this class of compounds are very rare. Only two compounds, pongamosides A (**22**) and B (**23**), have been reported from *Pongamia pinnata* fruits.[2]

2.2 Flavonols

Out of the 24 furanoflavonols isolated, karanjin (**31**) has been studied extensively and found to be hypoglycemic (Table 2). Oral administration at a dose of 2 mg Kg^{-1} per day for 7 days caused a reduction in blood glucose level both in normal and alloxan-induced diabetic rats. [43] It also showed antitubercular (suppressing growth of *Mycobacterium tuberculosis* H37Rv at 10–5 dilutions),[44] antifungal,[5] antibacterial, phytotoxic[45] and stimulant of CNS (LD_{50} 14–32) activities.[46] Apart from these activities, karanjin is also a nitrification inhibitor,[47] juvenomimetic,[48] and synergist to insecticides.[49] It was found to hemolyze red cells with release of LDH (lactate dehydrogenase).[50] Pongapin (**32**) was also found to be a synergist for insecticides.[51] There is only one report of the isolation of furanoflavonol glycoside, pongamoside C (**53**), from the fruits of *Pongamia pinnata*.[2]

2.3 Chalcones/dihydrochalcones

Four chalcones and three dihydrochalcones have been isolated (Table 3). All of them have an angular fused furan ring except **58** which was isolated from *Lonchocarpus subglaucescens* roots and has linear fusion of the furan ring.[62] Purpuritenin-A (**56**) and purpuritenin-B (**57**) have methyl substitution at the C-4 of ring-B.[53] Twigs of *Piper longicaudatum* showed antibacterial activity and activity guided fractionation afforded longicaudatin (**61**) along with other dihydrochalcones.[206]

2.4 Dibenzoylmethanes

There are few naturally occurring dibenzoylmethanes[65] and as a subclass, furanodibenzoylmethanes are much less prominent in nature (Table 4). Most of these diketones have been isolated from the *Pongamia*, *Tephrosia*, *Millettia* and *Lonchocarpus* genera except ovalitenone (**63**), which is isolated from *Rhus chinensis*.[4] Amongst these diketones, pongamol (**61**) has been explored extensively and found to have sedative and depressant (LD_{50} 17.14 mg kg^{-1})[46] and quinone reductase (CD 6.1 μM, IC_{50} 18.7 μM, CI 3.1) activities[66] and is commercially used in cosmetic and sun-screen preparations.[67,68] Ovalitenone or glabra-I (**63**) has cytotoxic activity against human cancer cells.[69] SAR studies have revealed that β-diketone groups linked to two benzoyl moieties are essential for inhibition of aflatoxicol formation.[70] Pongamol (**61**) was also found to be synergistic to insecticides[49] and to hemolyze red cells with release of LDH.[50] Compound **65**, isolated from *Lonchocarpus latifolius* roots, was subjected to a brine shrimp lethality test. It was active against *B. subtilis*, *A. niger* and *Cladosporium cladosporioides* with LC_{50} (mg ml^{-1}) 2.69.[16]

2.5 Aurones/auronols

Six aurones and auronols having furan rings anellated to C-6, 7 have been isolated from *Derris obtuse* roots (Table 5). No pharmacology has been reported for these compounds so far.

2.6 Isoflavones

Two isoflavones belonging to this category have been isolated from *Neorautanenia edulis* root bark without any mention of their pharmacology (Table 6).

2.7 Flavanones/flavanonols/flavans

These compounds were reported in *Lonchocarpus* and *Derris* species along with two compounds (**87** and **100**) from *Millettia erythrocalyx* roots (Table 7). The relative stereochemistries of most of these compounds have been established by coupling constant measurements whereas **86, 87, 90**[62] and **100**[18] were characterized by NOE difference experiments and Cotton effects observed in their ORD curves. No pharmacology has been reported for these compounds.

2.8 Pterocarpans

Furanopterocarpans have been isolated from *Neorautanenia*, *Erythrina* and *Pachyrrhizus* species (Table 8). One C-prenylated analogue, erybraedin E (**101**), was reported from *Erythrina mildbraedii*.[75] Neobanol (**102**) was a C-6a-hydroxylated pterocarpan

Table 1

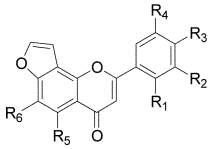
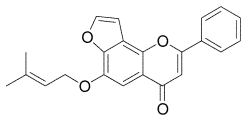
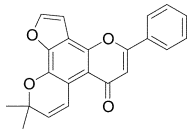
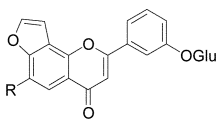
Compounds/trivial names	Source	Ref.
		
1. $R_1 = R_2 = R_3 = R_4 = R_5 = R_6 = H$; lanceolatin	*Tephrosia lanceolata*	8
	Millettia ovalifolia	9
	Millettia sanagana	7
	Pongamia glabra	10
	Pongamia pinnata	1
	Derris mollis	11
	Tephrosia purpurea	12
	Tephrosia falsiformis	13
	Lonchocarpus acida	14
	Tephrosia hamiltonii	15
	Desmodium sequax	3
	Lonchocarpus latifolius	16
	Millettia pachycarpa	17
	Millettia erythrocalyx	18
	Millettia leucantha	6
2. $R_1 = R_2 = R_3 = R_4 = R_5 = H$, $R_6 = OCH_3$; kanjone	*Pongamia glabra*	19
	Pongamia pinnata	1
	Tephrosia purpurea	20
	Millettia sanagana	7
3. $R_1 = R_2 = R_5 = R_6 = H$, R_3, $R_4 = –OCH_2O–$; prongaglabrone	*Pongamia glabra*	21
	Pongamia pinnata	1
	Derris mollis	11
	Lonchocarpus latifolius	16
	Millettia erythrocalyx	22
4. $R_1 = R_2 = R_4 = R_5 = R_6 = H$, $R_3 = OCH_3$	*Pongamia glabra*	23
	Derris mollis	11
5. $R_1 = R_5 = R_6 = H$, $R_2 = OCH_3$, $R_3 = R_4 = –OCH_2O–$	*Pongamia glabra*	24
	Desmodium sequax	3
6. $R_1 = R_3 = R_4 = R_5 = R_6 = H$, $R_2 = OH$	*Pongamia glabra*	25
	Pongamia pinnata	1
7. $R_1 = R_2 = R_3 = R_4 = R_6 = H$, $R_5 = OH$; pongaglabol	*Pongamia glabra*	26
	Pongamia pinnata	1
	Millettia erythrocalyx	18
	Millettia peguensis	27
	Tephrosia purpurea	28
8. $R_1 = R_2 = R_3 = R_4 = R_6 = H$, $R_5 = OCH_3$; pongaglabol methyl ether	*Pongamia glabra*	24
	Pongamia pinnata	1
	Millettia pachycarpa	29
	Millettia sanagana	7
	Ochna squarrosa	30
9. $R_2 = R_3 = R_4 = R_5 = R_6 = H$, $R_1 = OCH_3$	*Pongamia glabra*	31
10. $R_1 = R_2 = R_4 = R_5 = R_6 = H$, $R_3 = OH$; isopongaglabol	*Pongamia glabra*	32
11. $R_1 = R_2 = R_4 = R_5 = H$, $R_3 = OH$, $R_6 = OCH_3$; 6-methoxyisopongaglabol	*Pongamia glabra*	32
12. $R_1 = R_2 = H$, $R_3R_4 = –OCH_2O–$, $R_5 = R_6 = OCH_3$	*Derris araripensis*	33
13. $R_1 = R_3 = R_4 = R_5 = R_6 = H$, $R_2 = OCH_3$; pongol methyl ether	*Millettia erythrocalyx*	22
	Pongamia pinnata	1
14. $R_2 = R_3 = R_4 = R_5 = R_6 = H$, $R_1 = R_4 = OCH_3$; millettocalyxin C	*Millettia erythrocalyx*	22
	Pongamia pinnata	1
15. $R_1 = R_3 = R_6 = H$, $R_2 = R_4 = OCH_3$, $R_5 = OH$	*Diospyros peregrina*	36
16. $R_1 = R_4 = R_5 = H$, $R_2 = R_3 = –OCH_2O–$, $R_6 = OCH_3$	*Millettia ovalifolia*	9
17. $R_1 = R_2 = R_3 = R_4 = R_5 = H$, $R_6 = OH$	*Millettia ovalifolia*	9
18. $R_1 = R_4 = R_5 = R_6 = H$, $R_2 = R_3 = OCH_3$	*Pongamia pinnata*	37
19. $R_1 = R_3 = R_5 = R_6 = H$, $R_2 = R_4 = OCH_3$	*Millettia erythrocalyx*	38
		
20. Ovalifolin	*Millettia ovalifolia*	9
	Pongamia pinnata	34
	Ehretia ovalifolia	35
	Millettia erythrocalyx	22
		
21. Sanaganone	*Millettia sangana*	7
		
22. R = H; pongamoside A	*Pongamia pinnata*	2
23. R = OCH_3; pongamoside B	*Pongamia pinnata*	2

Table 1 (*Cont.*)

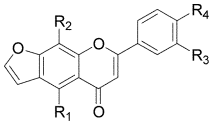
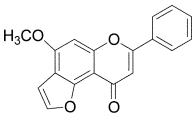
Compounds/trivial names	Source	Ref.
		
24. $R_2 = R_3 = R_4 = H$, $R_1 = OCH_3$; pinnatin	*Pongamia pinnata*	39
	Millettia pachycarpa	17
25. $R_1 = OCH_3$, $R_2 = H$, $R_3R_4 = –OCH_2O–$; gamatin	*Pongamia pinnata*	39
26. $R_1 = R_2 = R_4 = H$, $R_3 = OCH_3$; pongone	*Pongamia glabra*	40
27. $R_1 = R_3 = R_4 = H$, $R_2 = OCH_3$	*Pongamia glabra*	41
28. $R_1 = R_2 = R_3 = H$, $R_4 = OCH_3$; glabone	*Pongamia glabra*	42
		
29	*Pongamia glabra*	41

Table 2

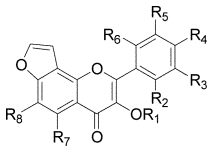
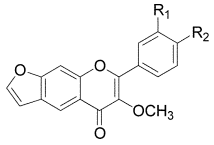
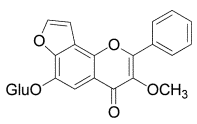
Compounds/trivial names	Source	Ref.
		
30. $R_1–R_8 = H$; karanjonol	*Pongamia glabra*	55
31. $R_1 = CH_3$, $R_2–R_8 = H$; karanjin	*Pongamia glabra*	52
	Pongamia pinnata	1
	Tephrosia purpurea	53
	Millettia leucantha	6
	Millettia pachycarpa	54
	Lonchocarpus latifolius	16
	Desmodium sequax	3
	Derris mollis	11
32. $R_1 = CH_3$, $R_3R_4 = –OCH_2O–$, $R_2 = R_5–R_8 = H$; pongapin	*Pongamia glabra*	56
	Pongamia pinnata	1
	Desmodium sequax	3
	Lonchocarpus latifolius	16
	Rhus chinensis	4
	Derris mollis	11
33. $R_1 = CH_3$, R_3, $R_4 = –OCH_2O–$, $R_5 = OCH_3$, $R_2 = R_6–R_8 = H$	*Pongamia glabra*	41
	Desmodium sequax	3
34. $R_1 = CH_3$, $R_7 = R_8 = OCH_3$, $R_2–R_6 = H$	*Derris araripensis*	33
	Derris urucu	58
	B. virgilioides	59
35. $R_1 = CH_3$, R_3, $R_4 = –OCH_2–$, $R_7 = R_8 = OCH_3$, $R_2 = R_5–R_6 = H$	*Derris araripensis*	33
36. $R_1 = CH_3$, $R_3 = R_4 = R_5 = OCH_3$, $R_2 = R_6 = R_7–R_8 = H$; pachycarin C	*Millettia pachycarpa*	17,60
37. $R_1 = CH_3$, $R_3 = OCH_3$, $R_2 = R_4–R_8 = H$; pachycarin D	*Millettia pachycarpa*	17,60
	Derris urucu	58
38. $R_1 = CH_3$, $R_2–R_7 = H$, $R_8 = OCH_3$	*Millettia ichthyochtona*	61
	Derris urucu	58
39. $R_1 = R_2 = R_3 = R_5–R_8 = H$, $R_4 = OCH_3$	*Derris urucu*	58
40. $R_1 = CH_3$, R_2, R_3, $R_5–R_7 = H$, $R_4 = R_8 = OCH_3$	*Derris urucu*	58
41. R_1, R_2, R_3, $R_5–R_7 = H$, $R_4 = OCH_3$, $R_8 = OH$	*Derris urucu*	58
42. $R_1–R_7 = H$, $R_8 = OCH_3$	*Derris urucu*	58
43. $R_1–R_6 = H$, $R_7 = OH$, $R_8 = OCH_3$	*Derris urucu*	58
44. $R_1 = CH_3$, $R_2 = R_6 = OCH_3$, $R_3–R_5$, R_7, $R_8 = OH$	*Millettia pachycarpa*	29
45. $R_1 = CH_3$, $R_3 = R_4 = OCH_3$, R_2, $R_5–R_8 = H$	*Millettia pachycarpa*	54
46. $R_1 = CH_3$, $R_4 = OCH_3$, R_2, R_3, $R_5–R_8 = H$	*Derris mollis*	11
47. $R_1 = CH_3$, R_2, R_4, $R_6–R_8 = H$, $R_3 = OH$, $R_5 = OCH_3$	*Pongamia pinnata*	1
48. $R_1 = CH_3$, R_2, R_4, $R_6–R_8 = H$, $R_3 = R_5 = OCH_3$	*Pongamia pinnata*	1
49. $R_1 = CH_3$, R_2, $R_4–R_8 = H$	*Pongamia pinnata*	1
50. $R_1 = CH_3$, $R_2–R_7 = H$, $R_8 = OH$	*Pongamia pinnata*	1
		
51. $R_1 = R_2 = H$; ponganone XI	*Pongamia pinnata*	34
52. $R_1R_2 = –OCH_2O–$	*Pongamia pinnata*	57
		
53. Pongamoside C	*Pongamia pinnata*	2

Table 3

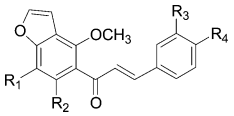
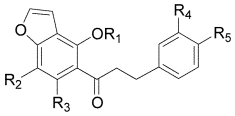
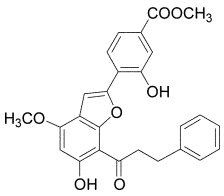
Compounds/trivial names		Source	Ref.
	**54**. $R_1 = R_2 = R_3 = R_4 = H$; ovalitenin A	*Millettia ovalifolia*	63
	55. $R_1 = OH$, $R_2 = H$, $R_3R_4 = –OCH_2O–$	*Derris obtusa*	64
	56. $R_1 = R_2 = R_3 = H$, $R_4 = CH_3$; purpuritenin	*Tephrosia purpurea*	53
	57. $R_1 = OCH_3$, $R_2 = OH$, $R_3R_4 = –OCH_2O–$	*Lonchocarpus subglaucescens*	62
	**58**. $R_1 = CH_3$, $R_2 = R_3 = H$, $R_4R_5 = –OCH_2O–$	*Lonchocarpus subglaucescens*	62
	59. $R_1 = H$, $R_2 = R_3 = OCH_3$, $R_4R_5 = –OCH_2O–$	*Derris araripensis*	33
	**60**. Longicaudatin	*Piper longiacudatum*	206

Table 4

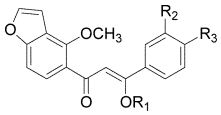
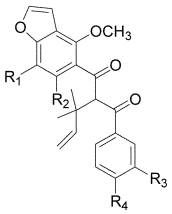
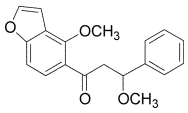
Compounds/trivial names		Source	Ref.
	**61**. $R_1 = R_2 = R_3 = H$; pongamol	*Pongamia glabra*	71
		Pongamia pinnata	1
		Tephrosia lanceolata	8
		Pongamia pinnata	56
		Tephrosia purpurea	12
		Tephrosia falsiformis	13
		Millettia sanagana	7
		Lonchocarpus latifolius	65
		Millettia peguensis	27
		Millettia erythrocalyx	18
	62. $R_1 = CH_3$, $R_2 = R_3 = H$; *O*-methylpongamol	*Tephrosia purpurea*	73
		Tephrosia hamiltonii	15
		Millettia ovalifolia	63
	63. $R_1 = H$, $R_2R_3 = –OCH_2O–$; glabra I/ovalitenone	*Pongamia glabra*	24
		Pongamia pinnata	72,1
		Millettia erythrocalyx	18
		Millettia peguensis	27
		Rhus chinensis	4
	64. $R_1 = CH_3$, $R_2R_3 = –OCH_2O–$; ponganone IX	*Pongamia pinnata*	34
	**65**. $R_1 = R_2 = R_3 = R_4 = H$	*Lonchocarpus latifolius*	65
	66. $R_1 = R_2 = H$, $R_3R_4 = –OCH_2O–$	*Lonchocarpus latifolius*	65
	67. $R_1 = R_2 = OCH_3$, $R_3 = R_4 = H$	*Lonchocarpus latifolius*	65
	**68**. Ovalitenone B	*Millettia ovalifoli*	62

Table 5

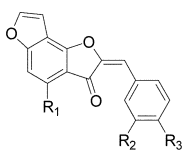
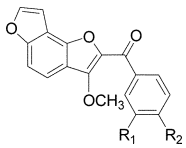
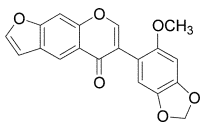
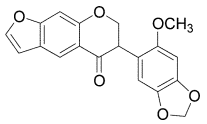
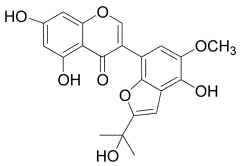
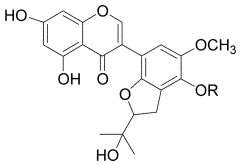
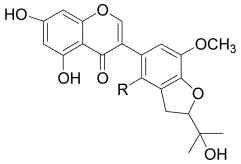
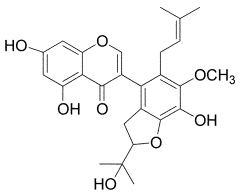
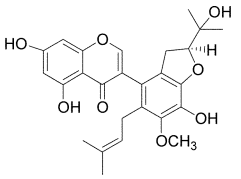
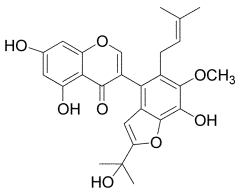
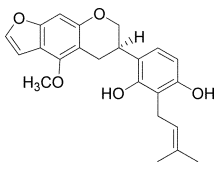
Compounds/trivial names		Source	Ref.
	**69**. $R_1 = R_2 = R_3 = H$	*Derris obtusa*	64
	70. $R_1 = OH$, $R_2 = R_3 = H$	*Derris obtusa*	64
	71. $R_1 = OCH_3$, $R_2 = R_3 = H$	*Derris obtusa*	64
	72. $R_1 = H$, $R_2R_3 = –OCH_2O–$	*Derris obtusa*	64
	**73**. $R_1 = R_2 = H$; derrirobostane A	*Derris obtusa*	64
	74. $R_1R_2 = –OCH_2O–$; derrirobostane B	*Derris obtusa*	64

Table 6

Compounds/trivial names		Source	Ref.
	**75**. Dehydroneotenone	*Neorautanenia edulis*	74
	**76**. Neotenone	*Neorautanenia edulis*	74
	**77**. Piscerisoflavone E	*Piscidia erythrina*	207
	**78**. R = H; piscerisoflavone A **79**. R = CH_3; piscerisoflavone F	*Piscidia erythrina* *Piscidia erythrina*	207 207
	**80**. R = H; piscerynetol F **81**. R = OH; piscerisoflavone B	*Piscidia erythrina* *Piscidia erythrina*	207 207
	**82**. Erythbigenol A	*Piscidia erythrina*	207
	**83**. Erythbigenol B	*Piscidia erythrina*	207
	**84**. Erythbigenol	*Piscidia erythrina*	207
	**85**. Glyasperin G	*Glycyrrhiza aspara*	208

with angular fusion of the furan ring.[76] Most of the compounds in this class have an angular fused furan ring except erosin (**105**). No biological activities have been reported for this class of compounds.

2.9 Rotenoids

The rotenoids are biosynthetically advanced isoflavonoids and construction of their angular A:B:C:D:E ring systems has been studied experimentally starting out from simple primary metabolites and passing through a series of mainly oxidative phases.[83] The rotenoid group of natural products is best known in the Leguminosae family "particularly species of the genera *Derris*, *Lonchocarpus*, *Milletia*, *Neorautanenia* and *Tephrosia*" though they are also found in certain unrelated families such as the Nyctaginaceae and the monocotyledonous Iridaceae (Table 9).[84] The biosynthesis of dihydrofuranorotenoids has been discussed with a review of isotopic labeling experiments[83]

Table 7

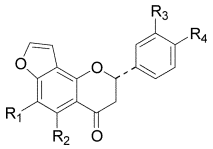
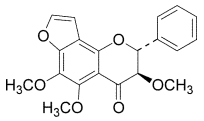
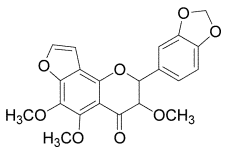
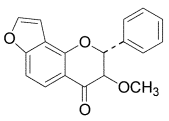
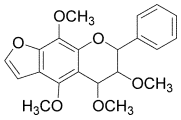
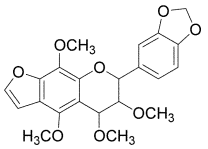
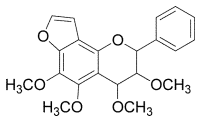
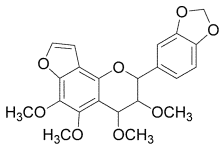
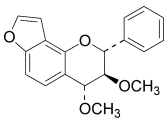
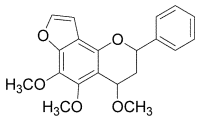
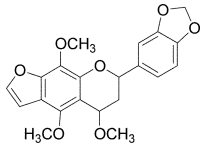
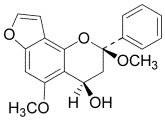
Compounds/trivial names		Source	Ref.
	**86**. $R_1 = R_2 = OCH_3$, $R_3 = R_4 = H$ **87**. $R_1 = OCH_3$, $R_2 = R_3 = R_4 = H$ **88**. $R_1 = OCH_3$, $R_2 = OH$, $R_3R_4 = –OCH_2O–$ **89**. $R_1 = R_2 = H$, $R_3R_4 = –OCH_2O–$	*Lonchocarpus subglaucescens* *Millettia erythrocalyx* *Lonchocarpus subglaucescens* *Derris araripensis* *Lonchocarpus latifolius*	62 18 62 33 16
	**90**	*Lonchocarpus subglaucescens*	62
	**91**	*Derris araripensis*	33
	**92**	*Lonchocarpus latifolius*	16
	2,3-*Trans*, 3,4-*trans* **93**	*Lonchocarpus subglaucescens*	62
	**94**	*Lonchocarpus subglaucescens*	62
	**95**	*Lonchocarpus subglaucescens* *Derris araripensis* *Derris obtusa*	62 33 64
	**96**	*Lonchocarpus subglaucescens*	62
	**97**	*Lonchocarpus latifolius*	16
	**98**	*Lonchocarpus subglaucescens*	62
	**99**	*Lonchocarpus subglaucescens*	62
	**100**	*Millettia erythrocalyx*	18

Table 8

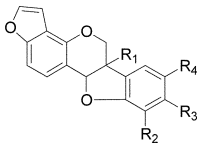
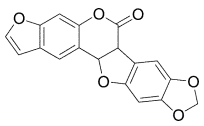
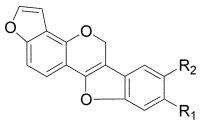
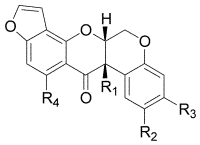
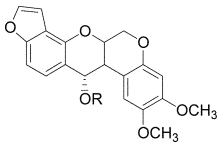
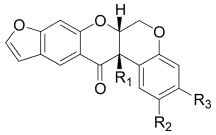
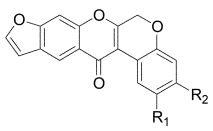
Compounds/trivial names		Source	Ref.
	**101**. $R_1 = R_4 = H$, $R_2 = –CH_2CH=C(CH_3)_2$, $R_3 = OH$; erybraedin E	*Erythrina mildbraedii*	75
	102. $R_1 = OH$, $R_2 = H$, $R_3R_4 = –OCH_2O–$; neobanol	*Neorautanenia amboensis*	76
	103. $R_1 = R_2 = R_4 = H$, $R_3 = OH$; neodunol	*Neorautanenia edulis*	77
	104. $R_1 = R_2 = H$, $R_3R_4 = –OCH_2O–$; neodulin	*Neorautanenia edulis*	78,79
	**105**. Erosin	*Neorautanenia amboensis* *Pachyrrhizus erosus*	80,81 82
	**106**. $R_1 = OH$, $R_2 = H$; neorauteen	*Neorautanenia edulis*	77
	107. $R_1R_2 = –OCH_2O–$; neoduleen	*Neorautanenia edulis*	77

Table 9

Compounds/trivial names		Source	Ref.
	**108**. $R_1 = R_2 = R_3 = R_4 = H$; pongarotene	*Pongamia pinnata*	45
	109. $R_1 = R_4 = H$, $R_2 = R_3 = OCH_3$; elliptone	*Lonchocarpus salvadorensis*	90
		Derris malaccensis	86
	110. $R_1 = OH$, $R_2 = R_3 = OCH_3$, $R_4 = H$	*Derris trifolia*	87
	111. $R_1 = H$, $R_2 = R_3 = OCH_3$, $R_4 = OH$; (+) malaccol	*Derris malaccensis*	91
	**112**. R = H; elliptinol	*Derris elliptica*	89
	113. R = Ac	*Derris oblonga*	88
	**114**. $R_1 = H$, $R_2 = R_3 = OCH_3$; erosone	*Pachyrrhizus erosus*	81
	115. $R_1 = H$, R_2 $R_3 = –OCH_2O–$; dolineone	*Neorautanenia amboensis*	93
	116. $R_1 = OH$, $R_2 = R_3 = OCH_3$; 12a-hydroxyerosone	*Pachyrrhizus erosus*	92
	117. $R_1 = OCH_3$, $R_2 = R_3 = OCH_3$; neobanone	*Neorautanenia amboensis*	76
	118. $R_1 = OH$, $R_2 = R_3 = –OCH_2O–$; 12a-hydroxydolineone	*Neorautanenia amboensis*	93
	119. $R_1 = OCH_3$, $R_2 = R_3 = –OCH_2O–$; 12a-methoxydolineone	*Neorautanenia amboensis*	93
	**120**. $R_1R_2 = OCH_3$; dehydroerosone	*Pachyrrhizus erosus*	92,81
	121. $R_1R_2 = –OCH_2O–$; dehydrodolineone	*Neorautanenia amboensis*	93

but there is no experimental proof for the biosynthesis of furanorotenoids apart from a hypothesis which stated that hydroxylation at 4′ of the dalpanol (**228**) and conversion of it to a better leaving group provides the hypothetical precursor of the furan ring-E rotenoid elliptone (**109**).[83]

These possibilities have not been tested experimentally in the rotenoid series but it has been shown by Tanaka *et al.* that a cell-free microsomal preparation from the fungus *Botrytis cinerea* converts the isoflavone luteone (from white lupin) into the epoxide and hence into the tertiary alcohol which resembles dalpanol.[85] Elliptone (**109**) was found to be antibacterial against *Helicobacter pylori* [MIC (mg ml^{-1}) 3.0][86] whereas pongarotene (**108**) showed antifungal, antibacterial and phytotoxic activities.[45] One recent report of furanorotenoids includes **110** from *Derris trifolia* that showed inhibitory activity on EBV-EA activation induced by TPA in Raji cells and was found to be equivalent to that of β-carotene without any cytotoxicity.[87]

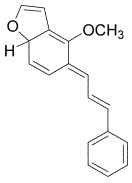
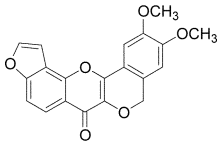
2.10 Miscellaneous

Two compounds, purpuriamethide (**122**) and pachycarin E (**123**), have characteristic skeletal features which exclude them from any classification (Table 10). Purpuriamethide is an unusual allydine benzofuran type of compound isolated from *Tephrosia purpurea* seeds[53] whereas pachycarin E isolated from *Millettia pachycarpa* roots seemed to be a rotenoid which may have originated from flavonols as their precursors.[17,53]

3 Dihydrofuranoflavonoids

This class of compounds has a hydrogenated furan ring anellated to the basic nucleus. Various substituted dihydrofurans have been isolated from plant sources. Their biosynthesis is not clear but isotopic studies towards the biosynthesis of rotenoids have revealed that there may be a possibility of epoxidation of the

Table 10

Compounds/trivial names		Source	Ref.
	**122**. Purpureamethide	*Tephrosia purpurea*	53
	**123**. Pachycarin E	*Millettia pachycarpa*	17

isoprenyl substituent and that subsequent cyclization may have resulted in the formation of these compounds.

3.1 Flavones/flavonols/chalcones/isoflavones

Compounds having various substituents in the dihydrofuran ring belong to this series. 2″(1-Hydroxy 1-methyl ethyl)-, 2″(isopropenyl)-, 2″-methyl-3″-dimethyl- and also 2″(1,2-diacetyl 2-methylpropane)- substitutions are known for the dihydrofuran ring (Table 11). Polystachin (**129**) isolated from *Tephrosa polystchya* is the only compound having a 2″(1,2-diacetyl 2-methyl propane)-substituted dihydrofuran ring.[94] Compounds **145, 150** and **179** were obtained from the microbial transformation of xanthohumol using the culture broth of *Pichia membranifaciens*.[95] Broussonol B (**141**) and Broussonol C (**142**) were tested by the MTT method for their cytotoxicity and found to be weakly cytotoxic against A549 and HCT-8 human tumor cell lines. For **141**, ED_{50} was 5.52 μg ml^{-1} (A549 cell line) and 8.80 μg ml^{-1} (HCT-8 cell line) whereas for **142**, ED_{50} was 7.77 μg ml^{-1} (A549 cell line) and 9.63 μg ml^{-1} (HCT-8 cell line).[96] Cedrediprenone (**151**) was found to inhibit luminol-enhanced chemiluminescence of reactive oxygen metabolites generated by human polymorphonuclear leucocytes activated with opsonized zymosan and to scavenge superoxide anions in a cell-free system, suggesting anti-inflammatory activity.[210] Derrisisoflavone C (**154**) has shown a relatively high antifungal activity at 250 μg ml^{-1}.[98] Fungitoxic activity and possible biogenetic pathways are suggested for isoflavonoids **155–160**.[99] Uncinnone B (**173**) isolated from *Desmodium uncinatum* induced germination of seeds of the parasitic weed *Striga hermonthica* (Del.) Benth., whereas uncinanone C (**174**) moderately inhibited radical growth thus providing a new alleopathic mechanism to prevent *S. hermonthica* parasitism.[97]

3.2 Flavanone/flavanonol/flavanes

The dihydrofuran ring of these compounds frequently has 2″(1-hydroxy 1-methyl ethyl)-, 2″(isopropenyl)- substitutions whereas two compounds, ugonin D (**192**) isolated from *Helminthostachys zeylanica*[104] and an isoflavan (+)-cyclomillinol (**197** isolated from *Millettia racemosa*), have 2″-methyl-3″-dimethyl- substitutions (Table 12).[118] Lonchocarpol E (**190**) has two 2-(1-hydroxy-1-methylethyl)-dihydrofuran rings anellated to the C-5, 6 and C-7, 8 positions and epimedkoreanin A (**186**) has one 2-(isopropenyl)-dihydrofuran at C-7, 8 and one 3-hydroxy-2-(1-hydroxy-1-methylethyl)-dihydrofuran ring at the C-4′, 5′ position in **186**.[119,120] Among other compounds isolated from *Broussonetia papyrifera*, flavanone (**181**) was identified as the most potent compound showing aromatase inhibitory activity (IC_{50} 0.1 μM as compared to the reference drug aminoglutethimide with IC_{50} 6.4 μM).[121] Phellodensin D (**180**) isolated from *Phellodendron chinense* and *Macaranga conifera* was tested for its inhibitory effect against cyclooxygenase 1 and 2, but was found to be inactive.[122] Dorsmanin F and its epimer epidorsmanin F (**183**) and dorsmanin G and its epimer epidorsmanin G (**184**) have been isolated from *Dorstenia manii* aerial parts and characterized as a diastereomeric mixture.[123,124] These prenylated flavonoids have antioxidant activity against LDL oxidation.[125] Similarly, lonchocarpol C_1/C_2 (**188**) and lonchocarpol D_1/D_2 (**189**) have been isolated from *Lonchocarpus minimiflorus* and *Lupinus luteus* but they have been separated as pure diastereomers and tested for their antifungal activity. Lonchocarpol D_1 showed strong antifungal activity whereas its diastereomer was weakly active.[126] Although lonchocarpol C_1 has less fungitoxic activity, it was more active than its diastereomer lonchocarpol C_2. Phellodensin A (**193**) and C (**194**) were reported to have antioxidant and antityrosinase activities.[127] Emoroidenone (**191**) and hildgerdtene (**200**) have shown strong feeding deterrent activity against *Chilo partellus*.[128]

3.3 Pterocarpanes

Five linear dihydrofurano fused pterocarpanes have been reported from species of *Millettia* and *Tephrosia*. Emoroidocarpan (**204**) has been reported to be an antifeedent against *Chilo partellus* (Table 13).[128]

3.4 Rotenoids

To be classified as a dihydrofuranorotenoid, a natural product contains the rotenoid basic structure with an anellated dihydrofuran ring as shown in Fig. 1. They are biosynthetically advanced isoflavonoids generated from simple metabolites through a series of complex, mainly oxidative stages.[83] These natural products are best known in the Leguminosae family "particularly species of the genera *Derris*, *Lonchocarpus*, *Milletia*, *Neorautanenia* and *Tephrosia*" though they are also found in certain unrelated families such as the Nyctaginaceae and the monocotyledonous Iridaceae (Table 14).[84] The best known member of the group is (−)-(6a*S*,12a*S*,5′*R*)-rotenone (**215**), which is well known as a fish poison. It is the major insecticidal and antifeedant component of commercially used insecticide "Derris" prepared from *Derris* and *Lonchocarpus* species.[138,139] Rotenone (or its 6, 7-dihydroxy derivative) binds to NADH–ubiquinone reductase (complex I)

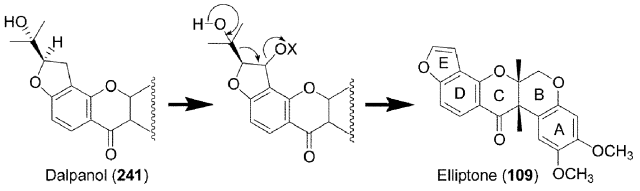


Fig. 1 Proposed hypothesis for the generation of ring-E.

Table 11

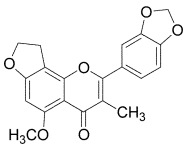
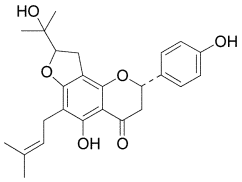
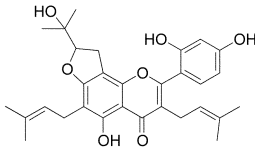
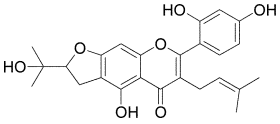
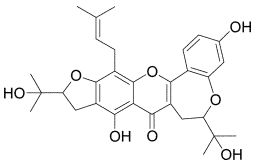
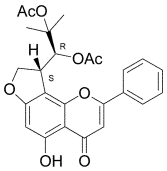
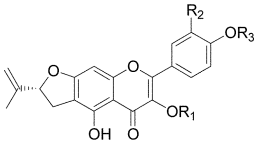
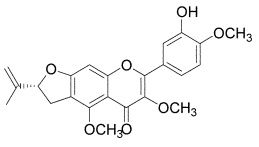
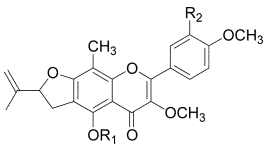
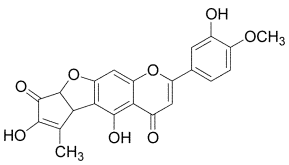
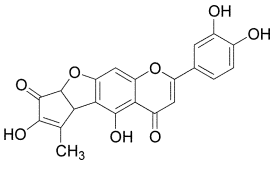
Compounds/trivial names		Source	Ref.
	**124**	*Hibiscus rosa-sinensis*	209
	**125**. Lupiniol A_1 & A_2	*Lupinus luteus*	210
	**126**. Artelastofuran	*Artocarpus elasticus* *Artocarpus lanceifolius*	100 101
	**127**. Mulberranol	*Morus alba*	102
	**128**. Carpelastofuran	*Artocarpus elasticus*	211
	**129**. Polystachin	*Tephrosia polystachya*	94
	**130**. $R_1 = R_3 = H$, $R_2 = OH$; velloquercetin **131**. $R_1 = H$, $R_2 = OH$, $R_3 = CH_3$; velloquercetin 4′, methylether **132**. $R_1 = CH_3$, $R_2 = R_3 = H$; vellokaempferol 3-methylether **133**. $R_1 = H$, $R_2 = OCH_3$, $R_3 = CH_3$; velloquercetin 3′, 4′-dimethylether **134**. $R_1 = R_3 = CH_3$, $R_2 = OCH_3$; velloquercetin 3, 3′, 4′-dimethylether	*Vellozia stipitata* *Vellozia stipitata* *Vellozia stipitata* *Vellozia graminifolia* *Vellozia graminifolia*	212 212 212 213 213
	**135**. Velloquercetin 3, 5, 4′-trimethylether	*Vellozia graminifolia*	214
	**136**. $R_1 = CH_3$, $R_2 = H$ **137**. $R_1 = H$, $R_2 = OH$ **138**. $R_1 = CH_3$, $R_2 = OCH_3$	*Vellozia stipitata* *Vellozia stipitata* *Vellozia stipitata*	212 212 212
	**139**. Torosaflavone	*Cassia torosa*	215
	**140**. Demethyltorosaflavone	*Cassia torosa*	216

Table 11 (*Cont.*)

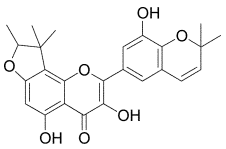
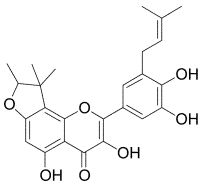
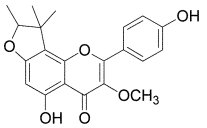
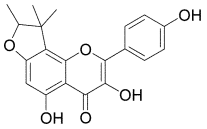
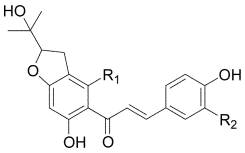
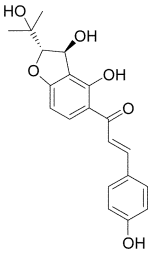
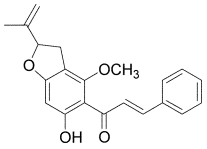
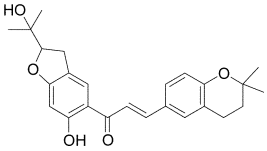
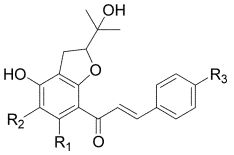
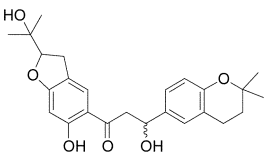
Compounds/trivial names		Source	Ref.
	**141**. Broussonol B	*Broussonetia kazinoki*	96
	**142**. Broussonol C	*Broussonetia kazinoki*	103
	**143**. Ugonin C	*Helminthostachys zeylanica*	104
	**144**. Ugonin F	*Helminthostachys zeylanica*	217
	**145**. $R_1 = OCH_3$, $R_2 = H$ **146**. $R_1 = H$, $R_2 = –CH_2CH=C(CH_3)_2$	Microbial transformation product *Dorstenia barteri*	95 107
	**147**. Brosimacutin-G	*Brosimum acutifolium*	105
	**148**. Cassichalcone	*Tephrosia crassifolia*	106
	**149**	*Dorstenia barteri*	107
	**150**. $R_1 = OCH_3$, $R_2 = H$, $R_3 = OH$ **151**. $R_1 = R_3 = H$, $R_2 = –CH_2CH=C(CH_3)_2$	Microbial transformation product *Cedrelopsis grevei*	95 218
	**152**	*Dorstenia barteri*	107

Table 11 (*Cont.*)

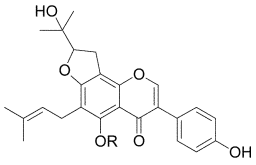
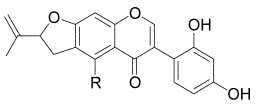
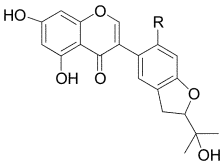
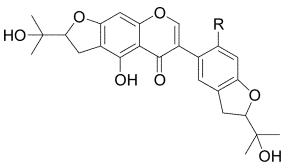
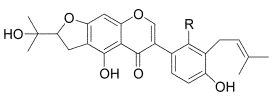
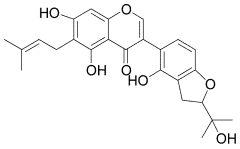
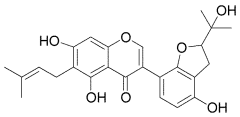
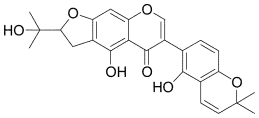
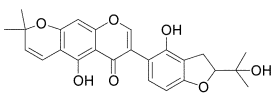
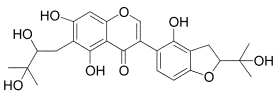
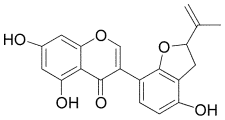
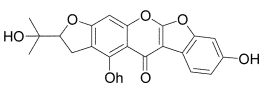
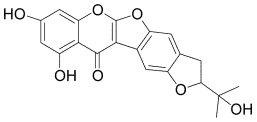
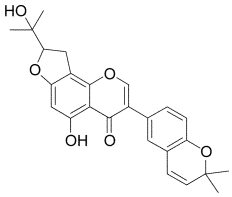
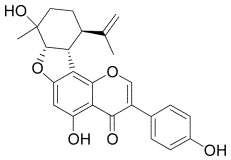
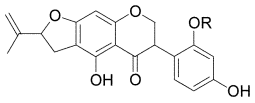
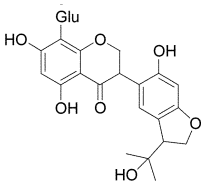
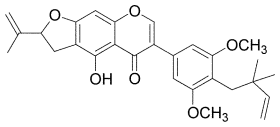
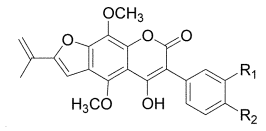
Compounds/trivial names		Source	Ref.
	**153**. R = H; euchrenone b_{10} **154**. R = CH_3; derrisisoflavone-C	*Euchresta japonica* *Derris scandens*	219 98
	**155**. R = OH; lupinisoflavone A **156**. R = H; lupinisoflavone B	*Lupinus albus* *Lupinus albus*	99 99
	**157**. R = H; lupinisoflavone C **158**. R = OH; lupinisoflavone D	*Lupinus albus* *Lupinus albus*	99 99
	**159**. R = H; lupinisoflavone E **160**. R = OH; lupinisoflavone F	*Lupinus albus* *Lupinus albus*	99 99
	**161**. R = H; lupinisoflavone G **162**. R = OH; lupinisoflavone H	*Lupinus albus* *Lupinus albus*	108 108
	**163**. Lupinisoflavone I	*Lupinus albus*	108
	**164**. Lupinisoflavone J	*Lupinus albus*	108
	**165**. Lupinisoflavone K	*Lupinus albus*	109
	**166**. Lupinisoflavone L	*Lupinus albus*	109
	**167**. Lupinisoflavone M	*Lupinus albus*	109
	**168**. Crotarin	*Crotalaria madurensis*	110
	**169**. Lupinalbin C	*Lupinus albus*	111
	**170**. Lupinalbin E	*Lupinus albus*	111

Table 11 (*Cont.*)

Compounds/trivial names		Source	Ref.
	**171**. Ulexone C	*Ulex europaeus*	112
	**172**. Ficusin B	*Ficus septica*	113
	**173**. R = H; uncinanone-B **174**. R = CH_3; uncinanone-C	*Desmodium uncinatum* *Desmodium uncinatum*	97 97
	**175**. Dalpanin	*Dalbergia paniculata*	114
	**176**. Pumilaisoflavone B	*Tephrosia pumila*	115
	**177**. R_1R_2 = –OCH_2O–; thonningine-A **178**. R_1 = H, R_2 = OCH_3; thonningine-B	*Millettia thonningii* *Millettia thonningii*	116 116

of the respiratory electron transport chain and is frequently used in biochemical experimentation.[140,141] These rotenoids have other interesting biological effects such as inhibition of the formation of microtubules from tubulin and anticancer activities.[142,143,144] Rotenone (**215**) isolated from *Derris elliptica* was broadly cytotoxic (ED_{50} 0.005 against P-388 lymphocytes of the leukemia cell line) against cultured P-388 and KB cells as well as a number of solid human tumor types (fibrosarcoma, lung, colon, breast cancer and melanoma).[144] Amorphigenin (**226**), 12a-hydroxyamorphigenin (Dalbinol, **229**), 12a-hydroxydalpanol (**242**) and 6′-*O*-β-D-glucopyranosyldalpanol (**241**) were isolated from *Amorpha fruticosa* and were tested for their cytotoxicity. They possess a considerable inhibitory effect on EBV-EA activation induced by TPA.[142] Structural proof for 6′-*O*-β-D-glucopyranosyldalpanol (**241**) and 12a-hydroxyamorphigenin (dalbinol, **229**) were produced using X-ray crystallographic data. These compounds, along with other rotenoids, have been tested for their cytotoxicity and it was found that **229** exhibits potent cytotoxicity (ED_{50} μg ml^{-1} <0.001) in six neoplastic cell lines.[143] There is ecological interest in the influence of rotenoids on certain plant–insect relationships and there is a long standing interest in their use as fish poisons for restocking waters with more valuable fish species or in indigenous fishing. Biosynthetic pathways leading to the rotenoid nucleus with an E-ring anellated to it has been discussed with full experimental details on isotopic labeling experiments.[83]

3.5 Miscellaneous

These compounds have structural features which are peculiar and thus, they cannot be classified among the categories mentioned above. Tephrorianin (**245**) has a lactone instead of a furan[175] and anastatin A (**246**) and B (**247**) have a benzofuran ring anellated to the flavonoid nucleus.[176] Anastatins A and B, which were isolated from *Anastatica hierochuntica*, have been reported to possess hepatoprotective effects on D-galactosamine induced cytotoxicity in primary cultured mouse hepatocytes (Table 15).[176]

4 Bisfuranoflavonoids

These secondary metabolites are characterized by the presence of a flavone-furo[2,3-*b*] furan ring system, which is exclusively produced by various species of *Tephrosia*. Neocalyxins A and B (**258**),[103,177] were isolated from the seeds of *Alpinia blephrocalyx* (Table 16). Apart from the bisfuran moiety, the flavonoid nucleus was commonly a flavone. There are two reports of flavanones [(+)-purpurin (**248**) and (−)-purpurin, (**249**)][178,179] and one of a chalcone [(+)-tephropurpin, **257**].[66] Purpurins or metallopurpurins were extensively studied for their potential as antitumor agents for photodynamic therapy.[180–182] (+)-Purpurin **248** and (+)-tephropurpin (**257**) were shown to induce quinine reductase activity where (+)-tephropurpin (**257**) was three times more active (CD μg ml^{-1} 0.15) than sulforaphane (CD μg ml^{-1}

Table 12

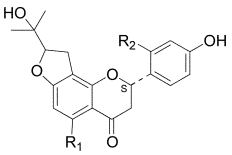
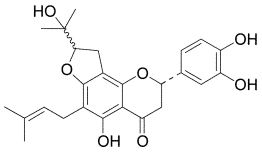
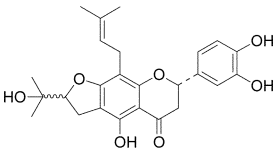
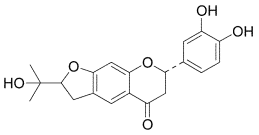
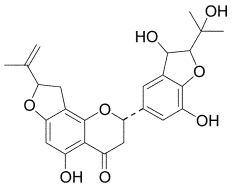
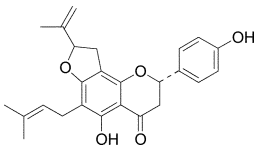
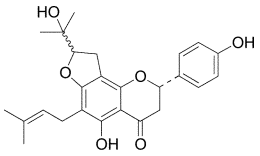
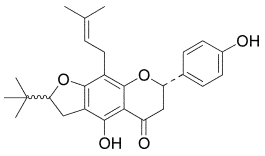
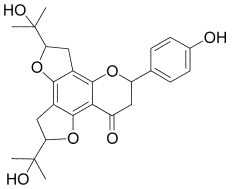
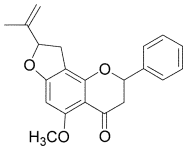
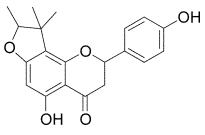
Compounds/trivial names		Source	Ref.
	**179**. $R_1 = OCH_3$, $R_2 = H$	Microbial transformation product	95
	180. $R_1 = OH$, $R_2 = H$; phellodensin-D	*Phellodendron chinense*	117
		Macaranga conifera	122
	181. $R_1 = H$, $R_2 = OH$	*Broussonetia papyrifera*	129,121
	182. $R_1 = R_2 = H$; brosimacutin-E	*Brosimum acutifolium*	105,130
	**183**. Dorsmanin-F & epidorsmanin-F	*Dorstenia mannii*	123,124
	**184**. Dorsmanin-G & epidorsmanin-G	*Dorstenia mannii*	123,124
	**185**. Velloeriodictyol	*Vellozia nanuzae*	220
	**186**. Epimedokoreanin A	*Epimedium koreanum*	119,131
	**187**. Lupineol	*Lupinus luteus*	126
	**188**. Lonchocarpol C-1/C-2	*Lonchocarpus minimiflorus*	120
		Lupinus luteus	126
	**189**. Lonchocarpol D-1/D-2	*Lonchocarpus minimiflorus*	120
		Lupinus luteus	126
	**190**. Lonchocarpol L-E	*Lonchocarpus minimiflorus*	120
	**191**. Emoroidenone	*Tephrosia emoroides*	128
	**192**. Ugonin D	*Helminthostachys zeylanica*	104

Table 12 (*Cont.*)

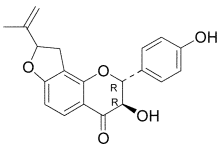
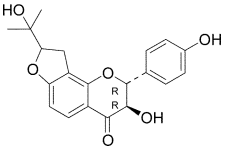
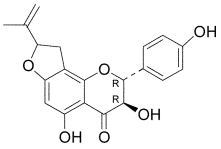
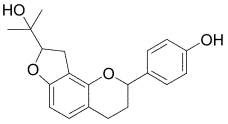
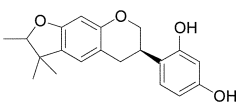
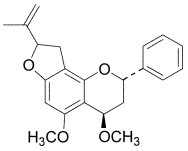
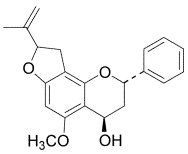
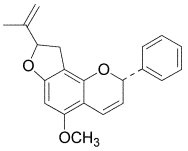
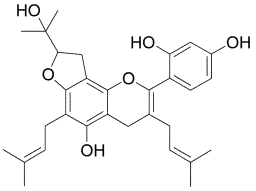
Compounds/trivial names		Source	Ref.
	**193**. Phellodensin-A	*Phellodendron amurense*	127
	**194**. Phellodensin-C	*Phellodendron amurense*	127
	**195**. Phellamurin	*Bursera leptophloeos* *Phellodendron chinense* *Phellodendron amurense*	132 122 127
	**196**. Brosimine-A	*Brosimum acutifolium*	133
	**197**. 3*R*-(+)-Cyclomillinol	*Millettia racemosa*	118
	**198**. Methylhildgardtol-A	*Tephrosia hildebrandtii*	134
	**199**. Methylhildgardtol-B	*Tephrosia hildebrandtii*	134
	**200**. Hildgardtene/abbottin	*Tephrosia emoroides* *Tephrosia hildebrandtii* *Tephrosia crassifolia*	128 134 106
	**201**. Artelastinin	*Artocarpus elasticus*	221

Table 13

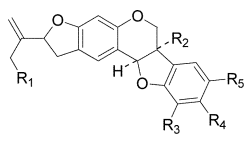
Compounds/trivial names		Source	Ref.
	**202**. $R_1 = R_2 = R_5 = H$, $R_3 = OH$, $R_4 = OCH_3$; pervilline	*Millettia pervilleana*	135
	203. $R_1 = R_2 = R_3 = H$, $R_4 = OCH_3$, $R_5 = OH$; pervillinine	*Millettia pervilleana*	135
	204. $R_1 = R_2 = R_3 = H$, R_4, $R_5 = –OCH_2O–$; emoroidocarpan	*Millettia pervilleana*	135
		Tephrosia emoroides	128
	205. $R_1 = R_3 = R_5 = H$, $R_2 = R_4 = OH$; isopropenyldihydrofuran	*Tephrosia vogellii*	136
	206. $R_1 = R_2 = OH$, $R_3 = H$, R_4,$R_5 = –OCH_2O–$; hildcarpin	*Tephrosia hildebrandtii*	137

Table 14

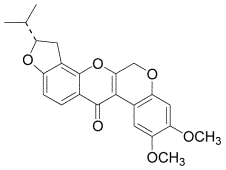
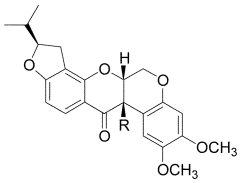
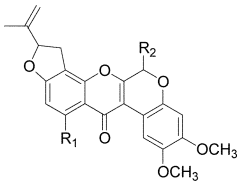
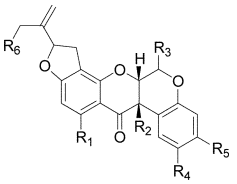
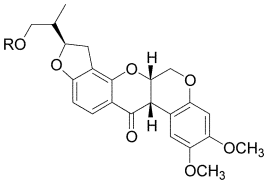
Compounds/trivial names		Source	Ref.
	**207**. Dehydrodihydrorotenone	*Tephrosia candida*	145
	**208**. R = OH; rotenolone	*Neorautanenia amboensis*	93
		Derris urucu	147
	209. R = OCH_3; 12-methoxyrotenolone	*Neorautanenia amboensis*	93
		Derris urucu	147
	**210**. $R_1 = R_2 = H$; dehydrorotenone	*Derris uliginosa*	148
		Tephrosia candida	149
		Neorautanenia amboensis	93
	211. $R_1 = OH$, $R_2 = H$; villosol	*Tephrosia villosa*	152,153
	212. $R_1 = H$, $R_2 = OH$; amorpholone	*Amorpha canescens*	150
	213. $R_1 = R_2 = OH$; dehydro-6-hydroxysumatrol	*Tephrosia villosa*	154
	214. $R_1 = H$, $R_2 = =O$; rotenonone	*Amorpha canescens*	150
		Neurautanenia amboensis	76
	**215**. $R_1 = R_2 = R_3 = R_6 = H$, $R_4 = R_5 = OCH_3$; rotenone	*Millettia dura*	155
		Neurautanenia amboensis	93
		Millettia pachycarpa	156
		Tephrosia vogelii	136
	216. $R_1 = R_3 = R_6 = H$, $R_2 = OH$, $R_4 = R_5 = OCH_3$; 12a-hydroxyrotenonone	*Neurautanenia amboensis*	93,76
		Derris urucu	147
		Millettia pachycarpa	156
		L. subglucescens	63
		Pachyrrhizus erosus	92
		Tephrosia pentaphylla	146
	217. $R_1 = R_2 = R_6 = H$, $R_3 = OH$, $R_4 = R_5 = OCH_3$; 6-hydroxyrotenonone	*Tephrosia pentaphylla*	146
	218. $R_1 = R_2 = R_3 = R_6 = H$, R_4, $R_5 = –OCH_2O–$; isomillettone	*Piscidia erythrina*	157
	219. $R_1 = R_3 = R_6 = H$, $R_2 = OH$, R_4, $R_5 = –OCH_2O–$; 12a-hydroxyisomillettone	*Neurautanenia amboensis*	76
	220. $R_1 = OH$, $R_2 = R_3 = R_6 = H$, R_4, $R_5 = OCH_3$; sumatrol	*Derris malaccensis*	151
		Tephrosia vogellii	136
	221. $R_1 = OH$, $R_2 = R_6 = H$, $R_3 = OH$, R_4, $R_5 = OCH_3$; villosin	*Tephrosia villosa*	152
	222. $R_1 = OH$, $R_2 = R_3 = OH$, R_4, $R_5 = OCH_3$, $R_6 = H$; villol	*Tephrosia villosa*	152
	223. $R_1 = OH$, $R_2 = R_6 = H$, $R_3 = OCH_3$, R_4, $R_5 = OCH_3$; villinol	*Tephrosia villosa*	152
	224. $R_1 = R_2 = OH$, $R_3 = R_6 = H$, R_4, $R_5 = OCH_3$; villosinol	*Tephrosia villosa*	153
	225. $R_1 = OH$, $R_2 = R_6 = H$, $R_3 = O$ R_4, $R_5 = OCH_3$; villosone	*Tephrosia villosa*	152
	226. $R_1 = R_2 = R_3 = H$, R_4, $R_5 = OCH_3$, $R_6 = OH$; amorphigenin	*Amorpha fruticos*	164,165
		Tephrosia vogellii	136
		Dalbergia monetaria	166
	227. $R_1 = R_2 = R_3 = H$, R_4, $R_5 = OCH_3$, $R_6 = OGlu$; amorphigenin *O*-β-D-glucopyranoside	*Amorpha sp.*	167
		Dalbergia paniculata	159
		Dalbergia monetaria	166
	228. $R_1 = R_2 = R_3 = H$, R_4, $R_5 = OCH_3$, $R_6 = OGlu$-Ara (1 → 6); amorphin	*Amorpha fruticosa*	164
	229. $R_1 = R_3 = H$, $R_2 = R_6 = OH$, R_4, $R_5 = OCH_3$; dalbinol	*Dalbergia monetaria*	166
		Dalbergia latifolia	172
	230. $R_1 = R_3 = H$, $R_2 = OH$, R_4, $R_5 = OCH_3$, $R_6 = OGlu$; dalbin	*Dalbergia latifolia*	172
		Dalbergia monetaria	166
	231. $R_1 = R_2 = R_3 = H$, $R_4 = OCH_3$, $R_5 = R_6 = OH$; 3-*O*-demethylamorphigenin	*Amorpha fruticosa*	171
	**232**. R = H; dihydroamorphigenin	*Amorpha fruticosa*	168,169
	233. R = Glu-Ara (1→ 6); amorphol	*Amorpha fruticosa*	170

Table 14 (*Cont.*)

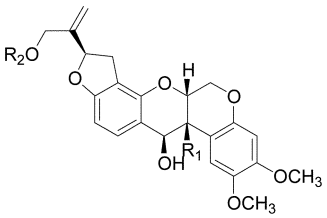
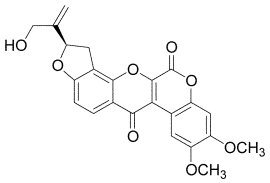
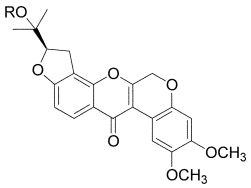
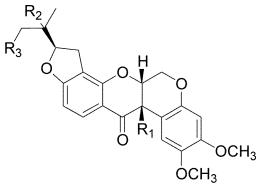
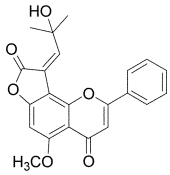
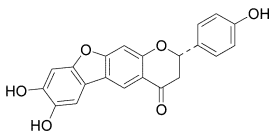
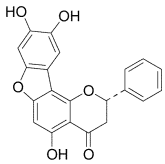
Compounds/trivial names		Source	Ref.
	**234**. $R_1 = R_2 = H$; (12*S*)-dihydrodalbinol **235**. $R_1 = OH$, $R_2 = Glu$; 12-dihydrodalbin **236**. $R_1 = H$, $R_2 = Glu$; dalcochinin	*Dalbergia monetaria* *Dalbergia monetaria* *Dalbergia cochinchinensis*	166 166 173
	**237**. 6-Ketodehydroamorphigenin	*Dalbergia sissoides*	174
	**238**. R = H; dehydrodalpanol **239**. R = Glu; dehydrodalpanol *O*-β-D-glucopyranoside	*Dalbergia paniculata* *Dalbergia paniculata*	160 161
	**240**. $R_1 = R_3 = H$, $R_2 = OH$; dalpanol **241**. $R_1 = R_3 = H$, $R_2 = OGlu$; dalpanol-*O*-β-D-glucopyranoside **242**. $R_1 = R_2 = OH$, $R_3 = H$; 12a-hydroxydalpanol **243**. $R_1 = H$, $R_2 = R_3 = OH$; amorphigenol **244**. $R_1 = H$, $R_2 = OH$, $R_3 = OGlu$; amorphigenol glucoside	*Dalbergia paniculata* *Tephrosia vogellii* *Dalbergia paniculata* *Amorpha fruticosa* *Amorpha fruticosa* *Amorpha fruticosa*	158 136 159 142,162 163 163

Table 15

Compounds/trivial names		Source	Ref.
	**245**. Tephrorianin	*Tephrosia hookeriana*	175
	**246**. Anastatin A	*Anastatica hierochuntica*	176
	**247**. Anastatin B	*Anastatica hierochuntica*	176

0.43), the positive control used for this assay, and has superior CI values (89.0) as a result of limited cytotoxicity.[66] The results for tephropurpurin showed its potential as a lead for development as a cancer chemopreventive agent. Glabratephrin (**259**) has been included in this context only for its being structurally alike and also a metabolite from the *Tephrosia* species. Glabratephrin (**259**) has shown significant antimicrobial and analgesic activity without ulceration.[183] (−)-Pseudosemiglabrin (**252**) displayed inhibitory effects on human platelet aggregation along with (−)-semiglabrin (**250**). (−)-Pseudosemiglabrin (**252**) has inhibited U46619 induced aggression by 85 ± 5% at a final concentration of 6.5 μg ml^{-1} whereas (−)-semiglabrin (−**250**) showed 70 ± 6% inhibition at a much higher dose (45 μg ml^{-1}).[184] These compounds have a minimum of three enantiomeric centers which made their absolute characterization challenging. Most of the papers dealing with the isolation of these compounds have shown relative stereochemistry. The absolute stereochemistries of some of the reported compounds have been established through total synthesis and some of the structures shown below are revised ones.[179,185]

Table 16

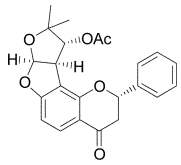
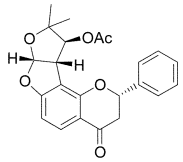
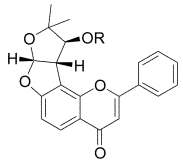
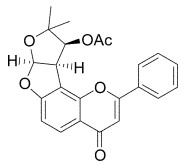
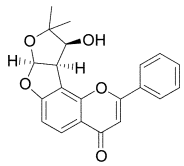
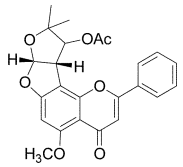
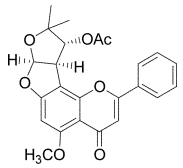
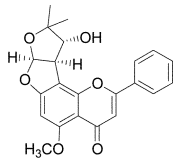
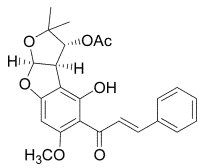
Compounds/trivial names		Source	Ref.
	**248**. (+)-Purpurin	*Tephrosia purpurea* Revised stereochemistry *Tephrosia hamiltonii*	178,66 179 15
	**249**. (−)-Purpurin	*Tephrosia purpurea*	20,178
	**250**. R = Ac; (−)-semiglabrin	*Tephrosia semiglabra* *Tephrosia apollinea* *Tephrosia purpurea* *Tephrosia nubica* *Tephrosia hookeriana* Revised stereochemistry	186,184 187,188 178,28 189 190,175 161,185
	251. R = H; (−)-semiglabrinol	*Tephrosia semiglabra* Revised stereochemistry *Tephrosia apollinea*	186 185 192,191
	**252**. (−)-Pseudosemiglabrin	*Tephrosia purpurea* *Tephrosia nubica* Revised stereochemistry	178 189 185
	**253**. (−)-Pseudosemiglabrinol	*Tephrosia apollinea* Revised stereochemistry	192 185
	**254**. Enantiomultijugin	*Tephrosia viciodes*	193
	**255**. Multijuigin	*Tephrosia multijuga*	194
	**256**. Multijuginol	*Tephrosia multijuga*	194
	**257**. (+)-Tephropurpurin	*Tephrosia purpurea*	66

Table 16 (*Cont.*)

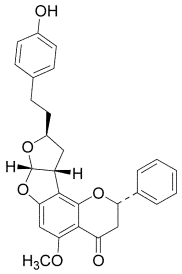
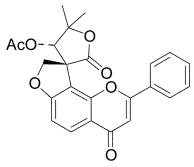
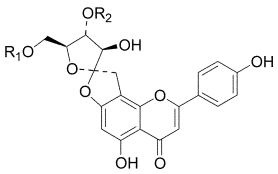
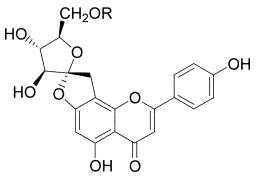
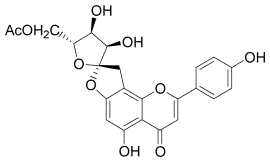
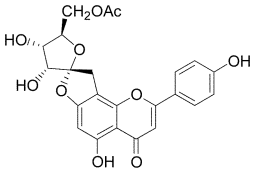
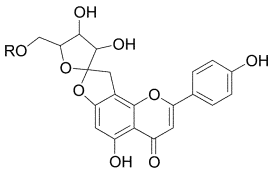
Compounds/trivial names		Source	Ref.
	**258**. Neocalyxin A & B (epimers at C-2)	*Alpinia blepherocalyx*	103,177
	**259**. Glabratephrin	*Tephrosia semiglabra* *Tephrosia apollinea* *Tephrosia nubica*	195 187,188 183

Table 17

Compounds/trivial names		Source	Ref.
	**260**. $R_1 = R_2 = H$; pinnatifin C **261**. $R_1 = Ac$, $R_2 = H$; pinnatifin D **262**. $R_1 = H$, $R_2 = Ac$; pinnatifin I	*Crataegus pinnatifida* *Crataegus pinnatifida* *Crataegus pinnatifida*	196,197 196,197 198
	**263**. R = H; pinnatifinoside A **264**. R = Ac; pinnatifinoside B	*Crataegus pinnatifida* *Crataegus pinnatifida*	199 199
	**265**. Pinnatifinoside C	*Crataegus pinnatifida*	199
	**266**. Pinnatifinoside D	*Crataegus pinnatifida*	199
	**267**. R = H; pinnatifida A **268**. R = Ac; pinnatifida B	*Crataegus pinnatifida* *Crataegus pinnatifida*	200 200

5 Ketohexofuranosides

In these rarely encountered compounds, furanose sugars are linked in a rather unusual manner to form both O- and C-glycosidic linkages to generate ketohexofuranoside ring structures. There are only nine compounds reported and all are from *Crataegus pinnatifida* belonging to the Rosaceae family (Table 17).[196–200] Stereochemical assignments for these compounds have been performed through ROESY experiments. All the compounds have α-D-fructofuranose as the glycosidic counterpart whereas pinnatifinosides A (**263**) and B (**264**) have β-D-allofuranose and α-D-allofuranose respectively. So far, no pharmacological profiles of these compounds have been reported.

6 Furanobiflavonoids

Biflavonoids with anellated furan rings have dimeric units generated from the fusion of a furan ring to different rings of the flavonoid moiety. Crassifolin (**271**) isolated from *Tephrosia crassifolia* has two 2″(isopropylene)-furanoflavan units dimerised

Table 18

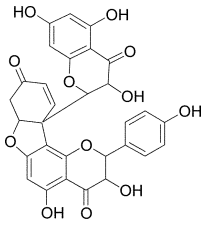
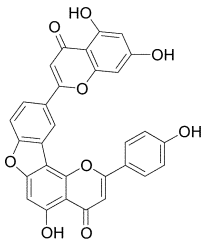
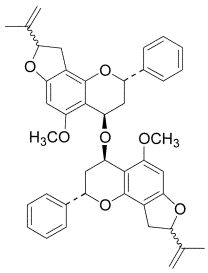
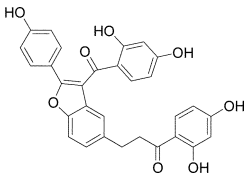
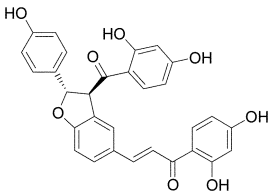
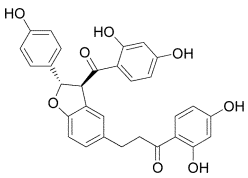
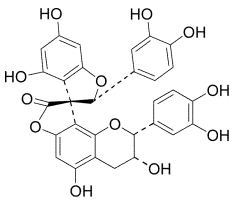
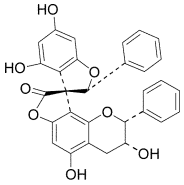
Compounds/trivial names		Source	Ref.
	**269**. Hypnumbiflavonoid A	*Hypnum cupressiforme*	201
	**270**	*Taxus baccata*	202
	**271**. Crassifolin	*Tephrosia crassifolia*	106
	**272**. Isolophirone C	*Ochna afzelii*	203
	**273**. Lophirone C	*Ochna afzelii*	203
	**274**. Dehydrolophirone C	*Ochna afzelii*	203
	**275**. Vitisinol L	*Vitis amurensis*	204
	**276**. Larixinol	*Larix gmelini*	205

Table 18 (*Cont.*)

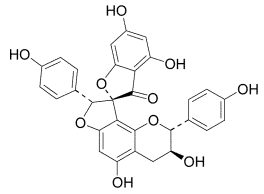
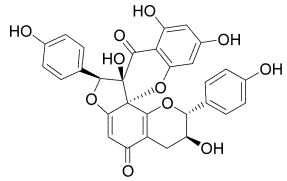
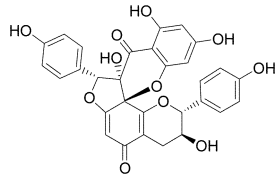
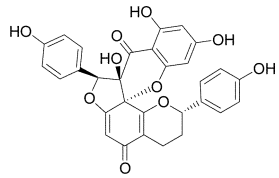
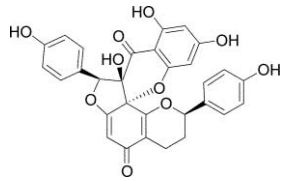
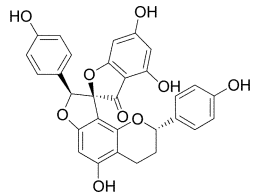
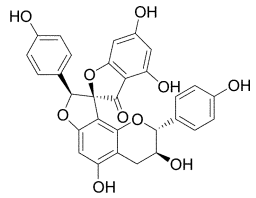
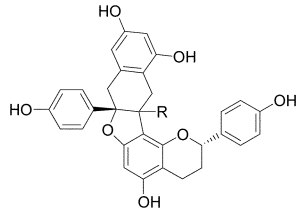
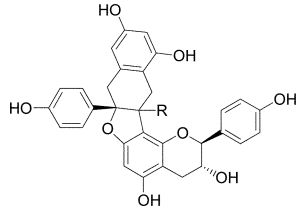
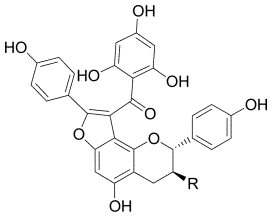
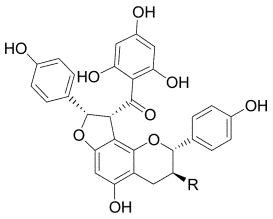
Compounds/trivial names		Source	Ref.
	**277**. Genkwanol-A	*Daphne genkwa*	222
	**278**. Genkwanol-B	*Daphne genkwa*	223
	**279**. Genkwanol-C	*Daphne genkwa*	224
	**280**. Daphnodorin-M	*Daphne odora*	225
	**281**. Daphnodorin-N	*Daphne odora*	225
	**282**. Daphnodorin-C	*Daphne odora*	226
	**283**. Daphnodorin-I	*Daphne odora*	227
	**284**. R = α-OH; daphnodorin-E **285**. R = β-OH; daphnodorin-F	*Daphne odora* *Daphne odora*	226 226
	**286**. R = α-OH; daphnodorin-G **287**. R = β-OH; daphnodorin-H	*Daphne odora* *Daphne odora*	227 227

Table 18 (*Cont.*)

Compounds/trivial names		Source	Ref.
	**288**. R = H; daphnodorin-A	*Daphne odora*	226
	289. R = OH; daphnodorin-B	*Daphne odora*	226
	**290**. R = H; daphnodorin-J	*Daphne odora*	228
	291. R = OH; dihydrodaphnodorin-B	*Daphne odora*	228

through the hydroxyl of the flavan moiety (Table 18). Compounds **272–274** are chalcones or dihydrochalcones dimerised to generate a dihydrofuran ring. The absolute configuration of spirobiflavonoids **277–291** has been determined by the collective use of NMR, X-ray, and a modified Mosher's method.[222–228] No pharmacology has been reported for these compounds.

7 Conclusion

Structural diversity among furanoflavonoids and their pharmacological studies have been reviewed. Flavonoids with an anellated furan ring have diverse biological activities including antifungal, antibacterial, antitubercular, anti-inflammatory, quinone reductase and cytotoxic, and they can be used as insecticide synergists and even in cosmetics and sun-screen. Amongst other classes, dihydrofuranocompounds, furanorotenoids and bisfuranoflavonoids have shown promising therapeutic potential for development as anticancer agents. They have shown very good cytotoxicity results against human tumor cells and other cell lines. Some of these compounds mentioned in the literature have promise for further development and optimization of their activities to obtain candidates for the drug discovery process.

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