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REVIEW ARTICLE

CHEMOSYSTEMATICS OF THE LAURACEAE*

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Abstract—The various chemical constituents of the Lauraceae are discussed in relation to the taxonomy of the family. Although there is a great paucity of data, the variation in the arylpropanoids, alkaloids, flavanoids and terpene constituents is in general in agreement with the subdivision of the family put forward by Kostermans.

INTRODUCTION

The lauraceae are a predominantly arboreous family.[3,4] Its species occur in tropical and subtropical regions and reach only exceptionally as far into temperate zones such as Chile (*Persea lingue* Nees) or southern Canada (*Lindera benzoin* Meissn.). Mankind has used the Lauraceae for their timber (itaúba—stone-wood—ex *Mezilaurus itauba* (Meissn.) Taub. and canela-tapinhoã ex *M. navalium* (Fr. Allem.) Taub. from Brazil, stink-wood ex *Ocotea bullata* E. Mey. from South Africa, nan-mu ex *Persea nanmu* Oliv. from China, iron-wood ex *Eusideroxylon zwageri* T. et B. from Indonesia); edible fruit (avocado ex *Persea americana* Miller from tropical America); seed fat (tangallak butter ex *Litsea sebifera* Pers. f. from Indochina, laurel berry fat ex *Laurus nobilis* L. from Europe); drugs (the coto barks ex *Aniba coto* (Rusby) Kosterm. and *A. pseudocoto* (Rusby) Kosterm. from Bolivia, demerara-greenheart ex *Ocotea rodiaei* (Schomb.) Mez from British Guyana, t'ien t'ai wu yao ex *Lindera strychnifolia* Vill. from China, camphor ex *Cinnamomum camphora* Sieb. from Formosa, China and Japan); spices (cinnamon ex *Cinnamomum zeylanicum* Nees from Ceylon, cassia ex *C. cassia* Blume from China, laurel ex *Laurus nobilis* L. from Europe, sassafras ex *Sassafras albidum* (Nutt.) Nees from North America); perfume oils (rosewood ex *Aniba duckei* Kosterm. from Brazil and ex *A. rosaeodora* Ducke from French Guyana, sassafras ex *Ocotea pretiosa* (Nees) Mez from Brazil). The leaves of the bay laurel, *Laurus nobilis* L., were used by the ancient Greeks and Romans to make wreaths with which to crown victorious warriors and athletes.

The quest for these materials has been intense at all times. Tales about a cinnamon-tree, most probably Casca preciosa (*Aniba canelilla* (H.B.K.) Mez), for instance, motivated the voyage of the Spanish soldiers from the Andes to the Amazon estuary about 1540.[5] So

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[1] W. B. Mors, O. R. Gottlieb and I. de Vattimo, *Nature, Lond.* **184**, 1589 (1959).

[2] A. Braga de Oliveira, O. R. Gottlieb, W. D. Ollis and C. T. Rizzini, *Phytochem.* **10**, 1863 (1971).

[3] A. J. G. H. Kostermans, *Reinwardtia* **4**, (2), 193 (1957).

[4] J. Hutchinson, *Evolution and Phylogeny of Flowering Plants*, p. 28, Academic Press, London (1969).

[5] O. R. Gottlieb, *Atas do Simpósio sôbre a Biota Amazônica* 4, (*Botânica*), 113 (1967).

efficiently indeed have some of these products been exploited, that the corresponding species are nearing extinction.

In spite of this considerable economic interest, only one account of the chemistry of the Lauraceae family is available, as a chapter of Hegnauer's monumental *Chemotaxonomie der Pflanzen.*[6] This considers the literature up to 1965.

The following is an attempt to insert the chemical profile of the Lauraceae within a dynamic morphological framework. Cronquist's[7] ideas concerning the evolutionary relationship within the flowering plants are shown in Fig. 1. It is seen that the Magnoliidae, presumably derived from pteridospermous ancestors which belong to an extinct order of the gymnosperms, are the basal complex from which the other angiosperms, dicotyledons and monocotyledons, have evolved.* The orders into which the Magnoliidae may be divided (Fig. 2), derive from the Magnoliales, whose major families are arranged by Hutchinson[4] according to the relationships sketched in Fig. 3. Cronquist does not agree with this system in all details. For the present discussion, however, it suffices to consider that the latter author recognizes two main groups of families: the magnoliaceous cluster (Magnoliaceae, Winteraceae, Degeneriaceae, Himantandraceae and Annonaceae) and the lauraceous cluster. The latter group comprises the Amborellaceae, Trimeniaceae, Monimiaceae, Calycanthaceae, Gomortegaceae and Hernandiaceae, besides the Lauraceae proper. These have been most thoroughly studied by Kostermans,[3] whose classification into subtribes is presented in a simplified form in Fig. 5. The complete system is reproduced in Table 8.

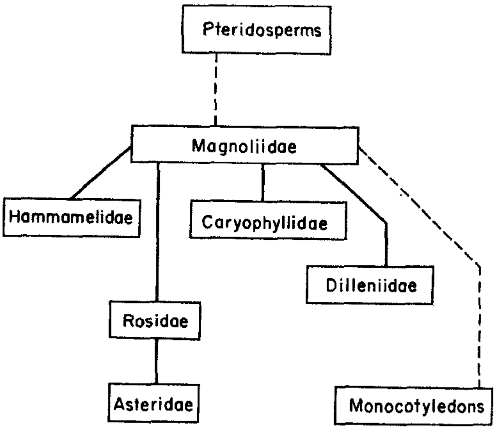

FIG. 1. PROBABLE DERIVATION AND RELATIONSHIPS OF THE SIX SUBCLASSES OF THE DICOTYLEDONS.

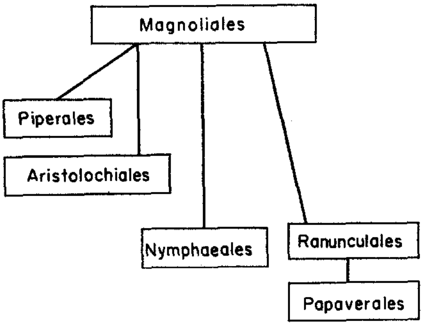

FIG. 2. PROBABLE RELATIONSHIPS AMONG THE ORDERS OF THE MAGNOLIIDAE.

ALKALOIDS

From the point of view of their extractives, Lauraceae species have been recognized for a long time as a source of alkaloids. According to Hegnauer,[8] benzyltetrahydroisoquinolines and aporphins are probably present in most of their members.

The benzyltetrahydroisoquinolines (I) are biosynthetically the simplest of these alka-

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* *Note added in proof.* For a contrasting view see K. KUBITZKY, *Taxon* **18**, 360 (1969). This and other comments by Dr. Kubitzky are gratefully acknowledged.

[6] R. HEGNAUER, *Chemotaxonomie der Pflanzen*, Vol. IV, Birkhäuser Verlag, Basel (1966).

[7] A. CRONQUIST, *The Evolution and Classification of Flowering Plants*, Nelson, London (1968).

[8] R. HEGNAUER, in *Comparative Phytochemistry* (edited by T. SWAIN), p. 211, Academic Press, London (1966).

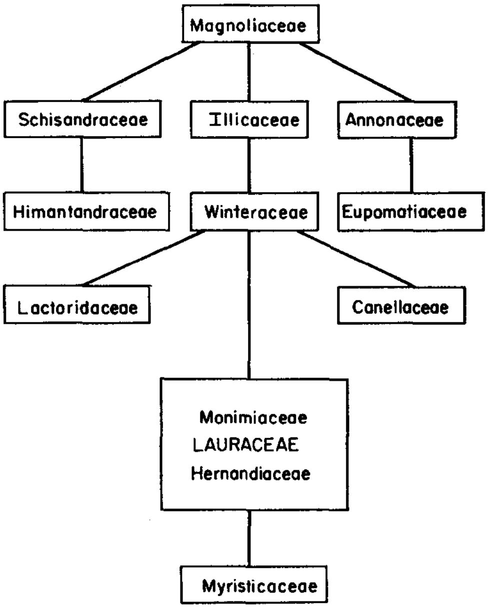
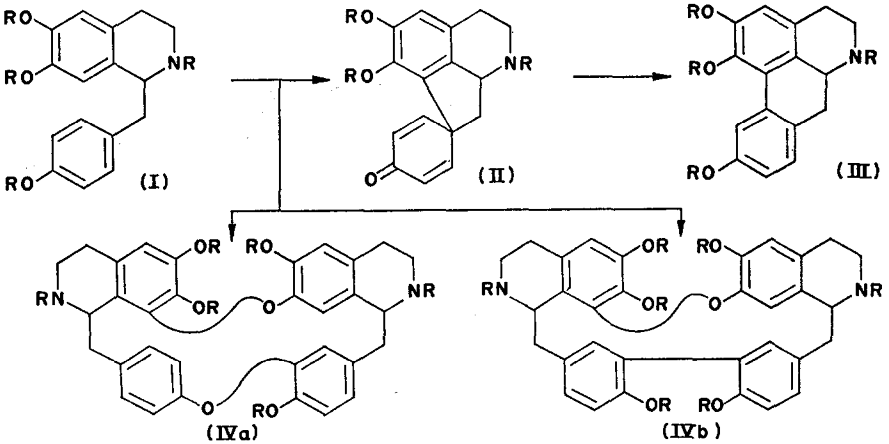


FIG. 3. PROBABLE RELATIONSHIPS AMONG SOME FAMILIES OF THE MAGNOLIALES.

loidal types. They derive by a few well known steps[9] from phenylalanine or tyrosine. Two major pathways are available for skeletal modifications of these primary alkaloids (Scheme 1A): Intramolecular oxidative coupling which leads via spirodienones (pro-aporphines, II) to aporphines (III), as well as intermolecular oxidative coupling which leads to bis-benzyltetrahydroisoquinolines (IV). Further pathways, of relatively more restricted occurrence, lead from aporphines (Scheme 1 B) to dehydroaporphines (V), 1-(ω-aminoethyl)-phenanthrenes (VI) and oxoaporphines (VII), as well as from benzyltetrahydroisoquinolines (Scheme 1 C) to benzylisoquinoline (VIII), dibenzopyrrocolin (IX), pavine (X) and morphinandienone (XI) types.[9a]



SCHEME 1. ALKALOIDAL TYPES OF THE LAURACEAE.
(A) BENZYLTETRAHYDROISOQUINOLINE DERIVATIVES

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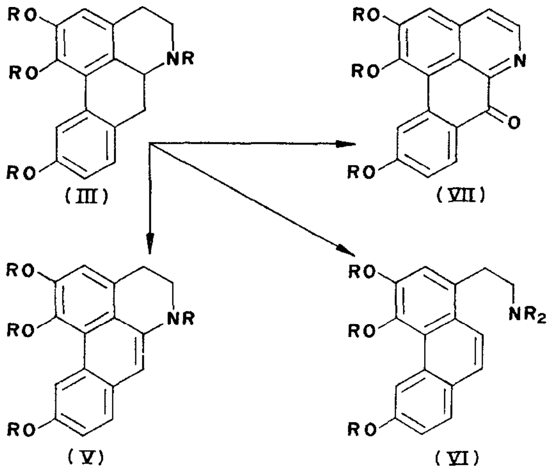
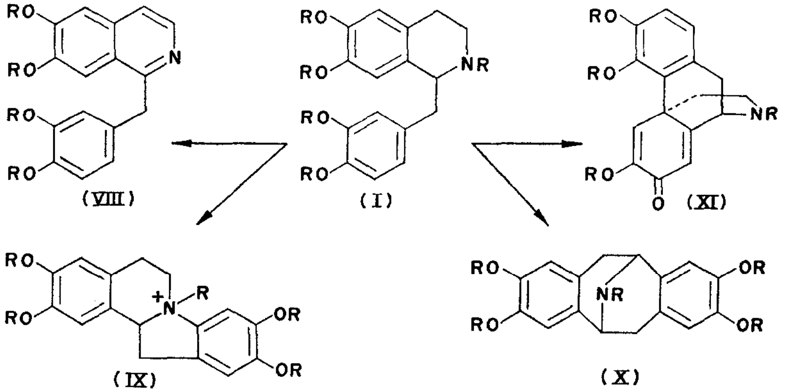
[9] L. KÜHN and S. PFEIFER, *Pharmazie* **20**, 659 (1965).

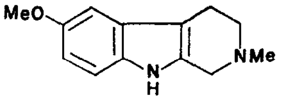
[9a] See additionally S. R. JOHNS, J. A. LAMBERTON, A. A. SIOUMIS and R. I. WILLING, *Austral. J. Chem.* **23**, 353 (1970).



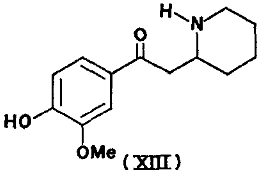
(B) Aporphine derivatives

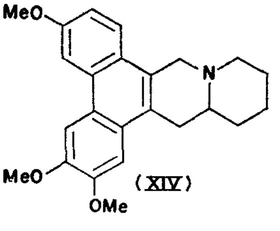


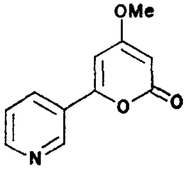
(C) Benzyltetrahydroisoquinoline derivatives



(XII)







(XV)

(D) Miscellaneous *N*-derivatives

With respect to the benzyltetrahydroisoquinoline derivatives: Lack of oxygenation at the indicated ring-B positions occurs in a few cases. Additional oxygenation, chiefly *ortho* to the indicated ring-B positions, occurs in many cases.

(I) Benzyltetrahydroisoquinolines. See MAGNOLIIDAE: Magnoliales (Magnoliaceae, Annonaceae, Hernandiaceae), Ranunculales (Ranunculaceae, Menispermaceae), Papaverales (Papaveraceae). ROSIDAE: Myrtales (Combretaceae), Sapindales (Rutaceae).[6,12]

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[12] H. G. Boit, *Ergebnisse der Alkaloid-Chemie bis* 1960, Akademie Verlag, Berlin (1961).

(II) Pro-aporphines (mecambrans). See MAGNOLIIDAE: Nymphaeales (Nymphaeaceae), Ranunculales (Menispermaceae), Papaverales (Papaveraceae). ROSIDAE: Euphorbiales (Euphorbiaceae).[9]

(III) Aporphines (and quaternized aporphines). See MAGNOLIIDAE: Magnoliales (Magnoliaceae, Annonaceae, Monimiaceae, Hernandiaceae), Aristolochiales (Aristolochiaceae), Nymphaeales (Nymphaeaceae), Ranunculales (Ranunculaceae, Berberidaceae, Menispermaceae), Papaverales (Papaveraceae). ROSIDAE: Euphorbiales (Euphorbiaceae), Rhamnales (Rhamnaceae), Sapindales (Rutaceae). DILLENIIDAE: Ebenales (Symplocaceae). LILIIDAE: Liliales (Liliaceae).[6,8,12,13]

(IV) Bisbenzyltetrahydroaporphines. See MAGNOLIIDAE: Magnoliales (Magnoliaceae, Annonaceae, Monimiaceae, Hernandiaceae), Ranunculales (Ranunculaceae, Berberidaceae, Menispermaceae). ROSIDAE: Myrtales (Combretaceae).[6,12]

(V) Dehydroaporphines.

(VI) 1-(ω-Aminoethyl)-phenanthrenes. See MAGNOLIIDAE: Ranunculales (Ranunculaceae).[12]

(VII) Oxoaporphines. See MAGNOLIIDAE: Magnoliales (Magnoliaceae, Monimiaceae).[8]

(VIII) Benzylisoquinolines.

(IX) Dibenzopyrrocolins.

(X) Pavines. See MAGNOLIIDAE: Papaverales (Papaveraceae).[14]

(XI) Morphinandienones. See MAGNOLIIDAE: Ranunculales (Menispermaceae), Papaverales (Papaveraceae). ROSIDAE: Euphorbiales (Euphorbiaceae).[9]

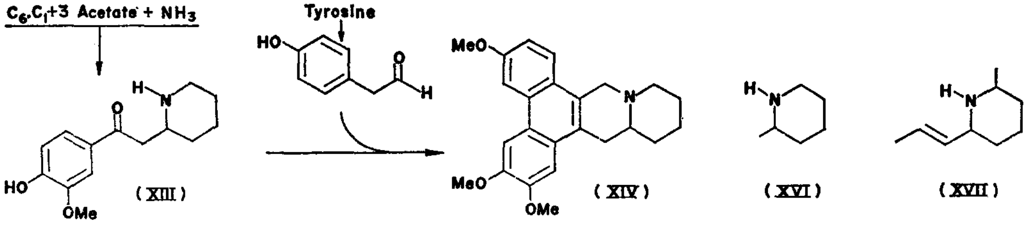
(XII) Tetrahydro-2-carbolins. See MAGNOLIIDAE: Magnoliales (Myristicaceae).[15a] CARYOPHYLLIDAE: Caryophyllales (Chenopodiaceae).[12]

(XIII) Pleurospermin. See HAMAMELIDAE: Urticales (Urticaceae).[15b]

(XIV) Cryptopleurin. See HAMAMELIDAE: Urticales (Urticaceae).[15b]

(XV) Anibine.

Only one tryptophane derived Lauraceae alkaloid (XII) has so far been described. Benzoic and acetic acids are held responsible for the origin of the pleurospermin (XIII)—cryptopleurin (XIV) pair of alkaloids. In the case of the latter compound, tyrosine again



SCHEME 2. POSSIBLE BIOSYNTHETIC ROUTE TO PLEUROSPERMIN AND CRYPTOPLEURIN.

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[13] M. Shamma and W. A. Slusarchyk, *Chem. Rev.* **64**, 59 (1964).

[14] F. R. Stermitz, in *Recent Advances in Phytochemistry* (edited by T. J. Mabry, R. E. Alston and V. C. Runeckles), Vol. 1, p. 161, Appleton–Century–Crofts, New York (1968).

[15] (a) S. R. Johns, J. A. Lamberton and J. L. Occolowitz, *Austral J. Chem.* **20**, 1737 (1967); (b) N. K. Hart, S. R. Johns and J. A. Lamberton, *Austral. J. Chem.* **21**, 1397, 2579 (1968).

TABLE 1. FREQUENCY OF ALKALOID

Sub family	Tribe	Genus	Total No. Spec.†
Lauroideae	Perseae		
	Perseineae	*Persea*‡	1
		Machilus	9
		Notaphoebe	1
		Alseodaphne	1
		Phoebe	1
	Beilschmiediineae	*Beilschmiedia*	1
	Cinnamomeae		
	Cinnamomineae	*Actinodaphne*	2
		Cinnamomum	2
		Ocotea	6
		Nectandra	1
	Anibineae	*Aniba*	4
	Litseeae		
	Litseineae	*Litsea*	3
		Neolitsea	3
	Laurineae	*Laurus*	1
		Lindera	1
	Cryptocaryeae		
	Cryptocaryineae	*Cryptocarya*	7
Cassythoideae			
		Cassytha	5

* The Table gives number of species containing constitutionally known alkaloids. References to unidentified alkaloids, such as Greshoff's "laurotetanin",[6] are not included. Additional genera in which such products were encountered are marked in Table 8.

† Total number of species in which identified alkaloids were located.

‡ *Phoebe porphyria* (Gris.) Mez from Argentina is a *Persea* species, according to Kosterman's criteria.[3]

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[16] A. M. KUCK, unpublished work. D. F. THEUMANN, Doctorate Thesis, Universidad de Buenos Aires (1968).

[17] M. TOMITA, T. H. YANG, K. N. GAIND and S. K. BAVEJA, *J. Pharm. Soc. Japan* **83,** 218 (1963); *Chem. Abs.* **59,** 2874 (1963).

[18] S. T. LU, *J. Pharm. Soc. Japan.* **83,** 19, 214 (1963); *Chem. Abs.* **59,** 3087, 3974 (1963).

[19] M. TOMITA, T. H. YANG and S. T. LU, *J. Pharm. Soc. Japan* **83,** 15 (1963); *Chem. Abs.* **59,** 3974 (1963).

[20] M. TOMITA and M. KOZUKA, *J. Pharm. Soc. Japan* **84,** 362 (1964); *Chem. Abs.* **61,** 4706 (1964).

[21] M. TOMITA, S. T. LU and P. K. LAN, *J. Pharm. Soc. Japan* **85,** 588 (1965); *Chem. Abs.* **63,** 12005 (1965).

[22] S. T. LU, *J. Pharm. Soc. Japan* **87,** 1278 (1967); *Chem. Abs,* **68,** 59777 (1968).

[23] S. T. LU, *J. Pharm. Soc. Japan* **87,** 1282 (1967); *Chem. Abs.* **68,** 47025 (1968).

[24] J. FRIEDRICHSONS and A. McL. MATHIESON, *Tetrahedron* **24,** 5785 (1968).

[25] S. R. JOHNS and J. A. LAMBERTON, *Austral. J. Chem.* **20,** 1277 (1967).

[26] P. S. CLEZY, A. W. NICHOL and E. GELLERT, *Experientia* **19,** 1 (1963).

[27] S. KRISHNA and T. P. GHOSE, *J. Indian Chem. Soc.* **9,** 429 (1932).

[28] M. TOMITA and M. KOZUKA, *J. Pharm. Soc. Japan* **84,** 365 (1964); *Chem. Abs.* **61,** 4706 (1964); E. GELLERT and R. E. SUMMONS, *Austral. J. Chem.* **23,** 2095, (1970).

[29] B. GILBERT, M. E. A. GILBERT, M. M. DE OLIVEIRA, O. RIBEIRO, E. WENKERT, B. WICKBERG, U. HOLLSTEIN and H. RAPOPORT, *J. Am. Chem. Soc.* **86,** 694 (1964).

[30] S. GOODWIN, A. F. SMITH and E. C. HORNING, *Chem. & Ind.* 691 (1960).

[31] M. P. CAVA, Y. WATANABE, K. BESSHO, M. J. MITCHELL, A. I. DA ROCHA, B. HWANG, B. DOUGLAS and J. A. WEISBACH, *Tetrahedron Letters* 2437 (1968).

[32] R. CHARUBALA, B. R. PAI, T. R. GOVINDACHARI and N. VISWANATHAN, *Chem. Ber.* **101,** 2665 (1968).

CONTAINING LAURACEAE SPECIES*

Benz.-Isoq. Deriv. A				Aporphine Deriv. B			Benz.-Isoq. Deriv. C				Miscellaneous *N*-Deriv. D				
I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV	XV	Ref.
1															16
9															17–22
1															23
1															24
		1													25
		1													26
		1													27
1		2													28
	1	5	1	1											29–36
											1				37
														4	38–40
		3													41–44
		3													45–47
		1													48
		1													49
1		2			1		1	1	1			1	1		50–55
		5				2				1					56–58

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[33] M. J. VERNENGO, *Experientia* **19,** 294 (1963).

[34] M. F. GRUNDON and J. E. B. MCGARVEY, *J. Chem. Soc.* **C,** 1082 (1966).

[35] K. C. CHAN, M. T. A. EVANS, G. H. HASSALL and A. M. W. SANGSTER, *J. Chem. Soc.* **C,** 2479 (1967).

[36] P. J. HEARST, M. SHAMMA, B. S. DUDOCK and R. J. SHINE, *J. Org. Chem.* **33,** 1229 (1968).

[37] B. GILBERT and D. DOS SANTOS FILHO, unpublished work. D. DOS SANTOS FILHO, Doctorate Thesis Faculdade de Farmácia e Odontologia de Ribeirão Preto, Estado de São Paulo (1969).

[38] W. B. MORS, O. R. GOTTLIEB and C. DJERASSI, *J. Am. Chem. Soc.* **79,** 4507 (1957).

[39] W. B. MORS and O. R. GOTTLIEB, *Anais Assoc. Brasil. Quim.* **18,** 185 (1959).

[40] W. B. MORS, M. TAVEIRA MAGALHÃES and O. R. GOTTLIEB, *Anais Assoc. Brasil. Quim.* **19,** 193 (1960).

[41] M. KOZUKA, *J. Pharm. Soc. Japan* **82,** 1567 (1962); *Chem. Abs.* **58,** 5989 (1963).

[42] M. TOMITA, S. T. LU and P. K. LAN, *J. Pharm. Soc. Japan* **85,** 593 (1965); *Chem. Abs.* **63,** 12005 (1965).

[43] S. T. LU and F. M. LIN, *J. Pharm. Soc. Japan* **87,** (1967); *Chem. Abs.* **61,** 117005 (1967).

[44] T. DUTTA, *J. Indian Chem. Soc.* **45,** 995 (1968).

[45] T. NAKASATO and S. NOMURA, *J. Pharm. Soc. Japan,* **77,** 816 (1957).

[46] M. TOMITA, S. T. LU and P. K. LAN, *J. Pharm. Soc. Japan* **85,** 662 (1965); *Chem. Abs.* **63,** 12005 (1965).

[47] W. H. HUI, S. N. LOO and H. R. ARTHUR, *J. Chem. Soc.* 2285 (1965).

[48] M. TOMITA, M. KOZUKA, E. NAKAGAWA and Y. MITSUNORI, *J. Pharm. Soc. Japan* **83,** 763 (1963); *Chem. Abs.* **59,** 15535 (1963).

[49] A. K. KIANG, and K. Y. SIM, *J. Chem. Soc.* **C,** 283 (1967).

[50] J. EWING, G. R. HUGHES, E. RITCHIE and W. C. TAYLOR, *Austral. J. Chem.* **6,** 78 (1953).

[51] R. G. COOKE and H. F. HAYNES, *Austral. J. Chem.* **7,** 99 (1954).

[52] C. K. BRADSHER and H. BERGER, *J. Am. Chem. Soc.* **80,** 930 (1958).

[53] J. W. LODER, *Austral. J. Chem.* **15,** 296 (1962).

[54] S. T. LU and P. K. LAN, *J. Pharm. Soc. Japan* **86,** 177 (1966); *Chem. Abs.* **64,** 17653 (1966).

[55] S. T. LU, *J. Pharm. Soc. Japan* **86,** 296 (1966), **87,** 1278 (1967); *Chem. Abs.* **65,** 2631 (1966); **68,** 59777 (1968).

[56] S. R. JOHNS and J. A. LAMBERTON, *Austral. J. Chem.* **19,** 297 (1966).

[57] S. R. JOHNS, J. A. LAMBERTON and A. A. SIOUMIS, *Austral. J. Chem.* **19,** 2331, 2339 (1966); **20,** 1457 (1967).

[58] M. P. CAVA, K. V. RAO, B. DOUGLAS and J. A. WEISBACH, *J. Org. Chem.* **33,** 2443 (1968).

enters the biosynthetic pathway (Scheme 2). Hegnauer[6] considers this scheme as a variant of the process which leads to the benzophenones of the genus *Aniba*. Constituents of this genus, including the pseudo-alkaloid anibine (XV) will be considered below.

If biosynthetic reasoning is related to the distribution of the diverse alkaloidal types in Lauraceae genera arranged according to Kostermans' system,[3] a fascinating regularity emerges (Table 1). The Perseae, located at the top of the system, seem capable of producing only the most primitive alkaloidal type I. In contrast, the Cryptocaryeae, located at the bottom, are able to operate a number of secondary modifications on the primitive benzyltetrahydroisoquinoline precursors leading to an array of types (III, VI, VIII, IX, X) and even to elaborate their own quite distinctive types XIII and XIV. The remaining tribes, Cinnamomeae and Litseeae, assume an intermediate position. It is easy to distinguish visually between Lauroideae (trees) and Cassythoideae (vines). Their alkaloid chemistry is nevertheless closely related, the distinctive features of the Cassythoideae being the presence of oxoaporphines (type VII) and of a morphine type alkaloid (XI). These considerations, although of course of a very tentative nature, due to the paucity of presently available data, indicate that the mapping of evolutionary relationships in the family is within reach.

The occurrence of simple phenylalanine derived alkaloids, such as benzyltetrahydroisoquinolines (I), aporphines (III) and bis-benzyltetrahydroisoquinolines (IV), is by no means limited to the Lauraceae. They seem, however, to have made their appearance in the plant kingdom with the Magnoliideae, whose orders they pervade profusely (Scheme 1, notes). From this most primitive subclass they spread sporadically into a few phylogenetically more advanced subclasses of the dicotyledons, and even the monocotyledons. The phylogenetic criterion herewith sketched for the Lauraceae may of course not prove helpful on a much wider scale for the definition of chemotaxonomic relations, if these common chemical characters arose by convergence or analogy.[8]

Does the occurrence of pleurospermin–cryptopleurin (XIII–XIV point to relationships in the other direction? This is, evidently, a very debatable point. The fact remains, however, that incorporation of a basic nitrogen into a polyketide chain is the reaction path by which the gymnosperms construct their alkaloids α-pipecolin (XVI) and pinidin (XVII).[10,11]

ARYLPROPANOIDS

Recent studies cast doubts on the ubiquity of alkaloids in the Lauraceae. Such compounds were not even encountered in several species of *Ocotea*, traditionally considered an alkaloid bearing genus, and only a pseudoalkaloid, anibine (XV), has so far been isolated from *Aniba* species. In what, by and large, appears to be substitutive presence, arylpropanoids (Scheme 3) appear. These range from cinnamoyl-derivatives (XVIII) to the relatively very rare cinnamyl-derivatives (XIX), as well as from the common allylbenzenes (XX and XXI) to a sole propenylbenzene (XXII). Birch[59] explained the predominance of allyl rather than propenylbenzenes in nature by preference of the biosynthetic sequence XXIX → XXX over XXIX → XXXI (Scheme 4). Could the ease of oxidation of propenylbenzenes contribute towards this disparity of distribution of the two groups of arylpropanoids?

Let me show why this question arises. Lauraceae species contain several bis-arylpropanoids (Scheme 3, B and C). With respect to their skeletons, sesamin (XXIII)[60] and

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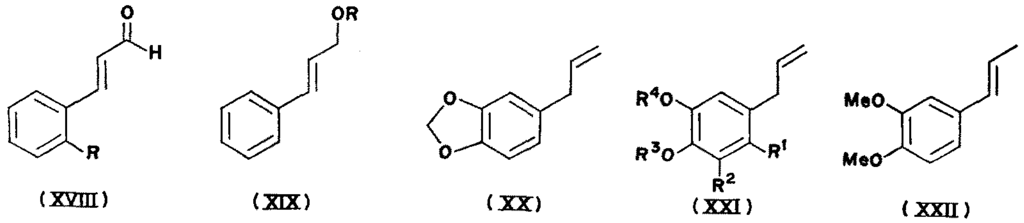
[10] W. H. TALLENT and E. C. HORNING, *J. Am. Chem. Soc.* **78**, 4467 (1956).

[11] R. K. HILL, T. H. CHAN and J. A. JOULE, *Tetrahedron* **21**, 147 (1965).

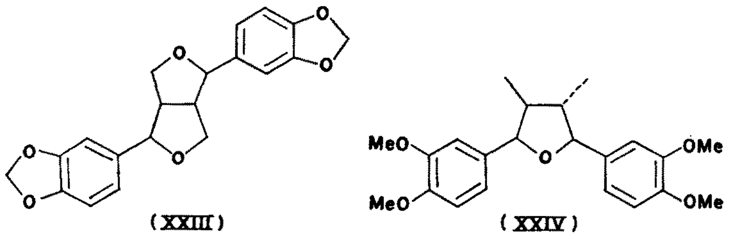
[59] A. J. BIRCH, in *Chemical Plant Taxonomy* (edited by T. SWAIN), p. 143, Academic Press, London (1963); see, however, L. CANONICA, P. MANITTO, D. MONTI and M. SANCHEZ A., *Chem. Commun.* 1108 (1971).

[60] B. CARNMALM, *Acta Chem. Scand.* **10**, 134 (1956).

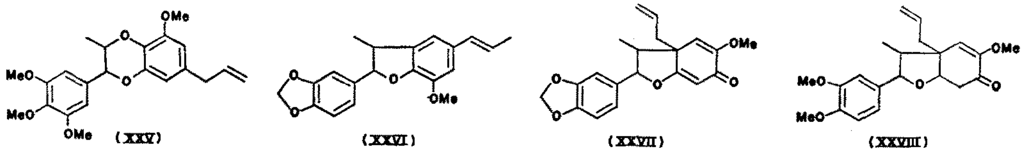


SCHEME 3. ARYLPROPANOIDS OF THE LAURACEAE.

(A) CINNAMIC ACID DERIVATIVES



(B) LIGNANS



(C) NEOLIGNANS

(XVIII) Cinnamoyl derivatives. R=H or OMe. Traces of the ubiquitous cinnamic, *p*-coumaric, caffeic, ferulic and sinapic acids have been located in several species,[6,119] but are not mentioned in the present context.

(XIX) Cinnamyl derivatives. R=H or Ac.

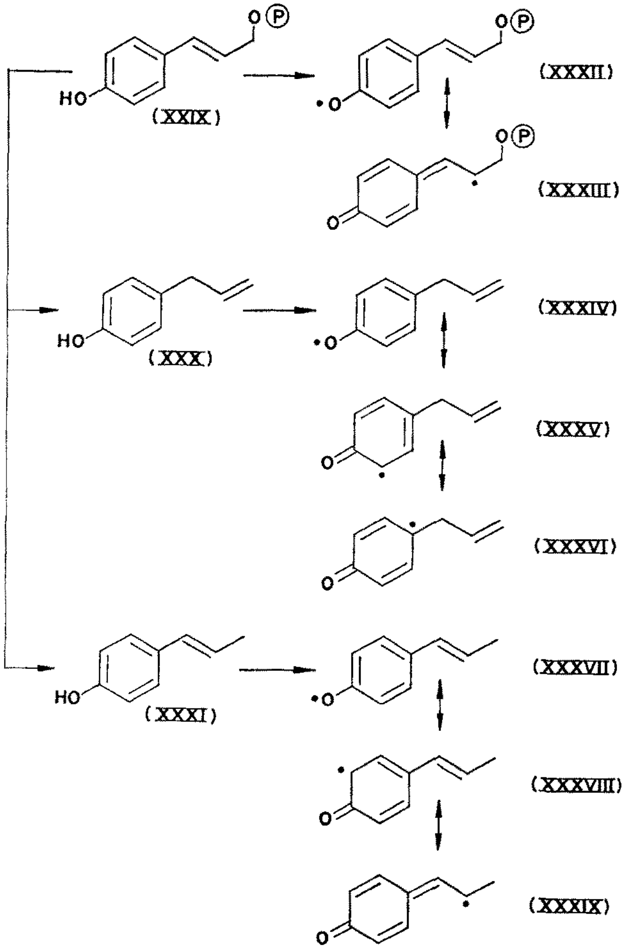
(XX), (XXI) Allylbenzenes. (XX) Safrole.[6,59,76,81,82]

	R^1	R^2	R^3	R^4
(XXIa)	H	H	OH	OMe
(b)	H	H	OMe	OMe
(c)	H	H	OAc	OMe
(d)	H	OMe	OMe	OMe
(e)	H	OMe	O—CH_2—O	
(f)	OMe	H	OMe	OMe

(XXII) Propenylbenzene.[94]

(XXIII), (XXIV) Lignans. See Gymnospermae—Cycadopsida (Ginkgoaceae). Coniferopsida (Cupressaceae, Pinaceae, Podocarpaceae). Taxopsida (Taxaceae). Angiospermae—MAGNOLIIDAE: Magnoliales (Magnoliaceae, Himantandraceae, Myristicaceae, Monimiaceae, Hernandiaceae), Piperales (Piperaceae), Aristolochiales (Aristolochiaceae), Ranunculales (Berberidaceae, Menispermaceae). HAMAMELIDAE: Fagales (Betulaceae). DILLENIIDAE: Ebenales (Symplocaceae). ROSIDAE: Myrtales (Myrtaceae), Euphorbiales (Euphorbiaceae), Sapindales (Rutaceae), Linales (Linaceae), Polygalales (Polygalaceae). ASTERIDAE: Gentianales (Apocynaceae), Polemoniales (Convolvulaceae), Scrophulariales (Oleaceae, Myoporaceae, Bignoniaceae, Pedaliaceae), Asterales (Compositae).[75]

(XXV)—(XXVIII) Neolignans. See MAGNOLIIDAE: Magnoliales (Magnoliaceae),[68] Piperales (Piperaceae).[69]



SCHEME 4. POSSIBLE BIOSYNTHETIC GENERATION OF C_6 . C_3-RADICALS.

veraguensin XXIV[61] have two arylpropanoid residues linked at the β-positions and belong, consequently, to the class of lignans.[62] In contradistinction, eusiderin (XXV),[63] licarin (XXVI),[64] burchellin (XXVII)[65] and porosin (XXVIII)[66] show considerable variation around the bis-arylpropanoid scheme, insofar as the β-carbon of one arylpropanoid moiety is linked to one of the three additional positions of the other, marked with an arrow in XL (Scheme 6C). In this diagram, all the alternative bridgehead positions are seen to be conjugated with the traditional lignan β-carbon bridgehead. An extension of the mechanistic interpretation given to lignan formation[62,67] will thus suffice to rationalize the biosynthesis of the neolignans, as I propose to designate these novel bis-arylpropanoids.

[61] N. S. CROSSLEY and C. DJERASSI, *J. Chem. Soc.* 1459 (1962).

[62] F. M. DEAN, *Naturally Occurring Oxygen Ring Compounds*, p. 39, Butterworths, London (1963).

[63] J. J. HOBBS and F. E. KING, *J. Chem. Soc.* 4732 (1960).

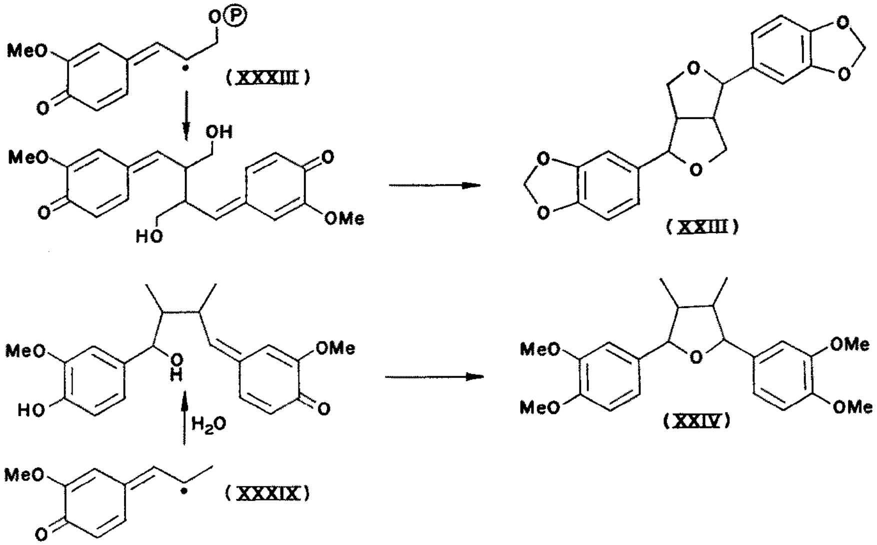
[64] R. G. CAMPOS CORRÊA and O. R. GOTTLIEB, unpublished work.

[65] O. ARAUJO LIMA, O. R. GOTTLIEB and M. TAVEIRA MAGALHÃES, *Phytochem.* **11**, (6) (1972).

[66] C. J. AIBA, R. BRAZ FILHO and O. R. GOTTLIEB, unpublished work.

[67] H. ERDTMAN, in *Recent Advances in Phytochemistry* (edited by T. J. MABRY, R. E. ALSTON, V. C. RUNECKLES), Vol. 1, p. 13, Appleton–Century–Crofts, New York (1968).

Indeed, Birch's cinnamyl pyrophosphate derivative XXIX can afford radicals located at the β-carbon in two ways (Scheme 4): Either by direct oxidation (to XXXII → XXXIII) or by reduction to a propenylbenzene (XXXI) and subsequent oxidation (to XXXVII → XXXIX). Both radicals (XXXIII and XXXIX) are highly stabilized and it becomes clear why their coupling products, the lignans (Scheme 5), are rather widespread plant constituents, while cinnamyl alcohols and propenylbenzenes are rarely found. The alternative and preferred, reduction path leads from the cinnamyl derivative (XXIX) to compounds (XXX) whose allyl side chain does not admit free radical formation at the β-carbon, and other radical sites (as in XXXIV, XXXV and XXXVI) have to be envisaged. Mixed coupling of these radicals with XXXIX leads to intermediates whose quinone methide moieties would be capable of aromatization through the intramolecular or intermolecular (H_2O) addition of an oxygen atom. In this way, the formation of all presently known neolignans from Lauraceae can be deduced (Scheme 6 A and B). Clearly, magnolol (XLI) ex *Magnolia obovata* Thunb. and *M. officinalis* Rehd. et Wilson,[68] as well as futoenone (XLII) and probably futoxide ($C_{18}H_{18}O_8$) ex *Piper futokadzura* Sieb. et Zucc.,[69] are also to be considered neolignans. Their natural derivation should involve analogous principles (Scheme 6 C).



SCHEME 5. POSSIBLE BIOSYNTHETIC ROUTES TO LIGNANS.

Nearly 40 years ago, Erdtman[70] already postulated the oxidation of coniferyl alcohol to different mesomeric radicals, whose coupling could yield quinone methides[67] such as XLIII and XLIV (X = H or OH, Scheme 7). These primary coupling products were supposed to be able to add water, coniferyl alcohol, or even another molecule of the same kind to yield products which, on further oxidation or polymerization, could give polymeric substances

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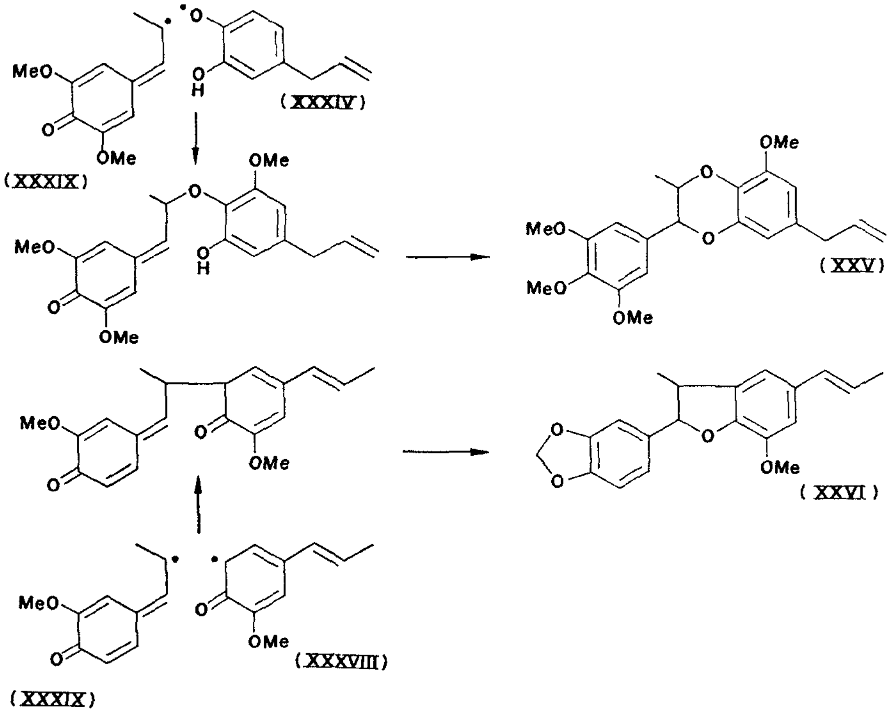
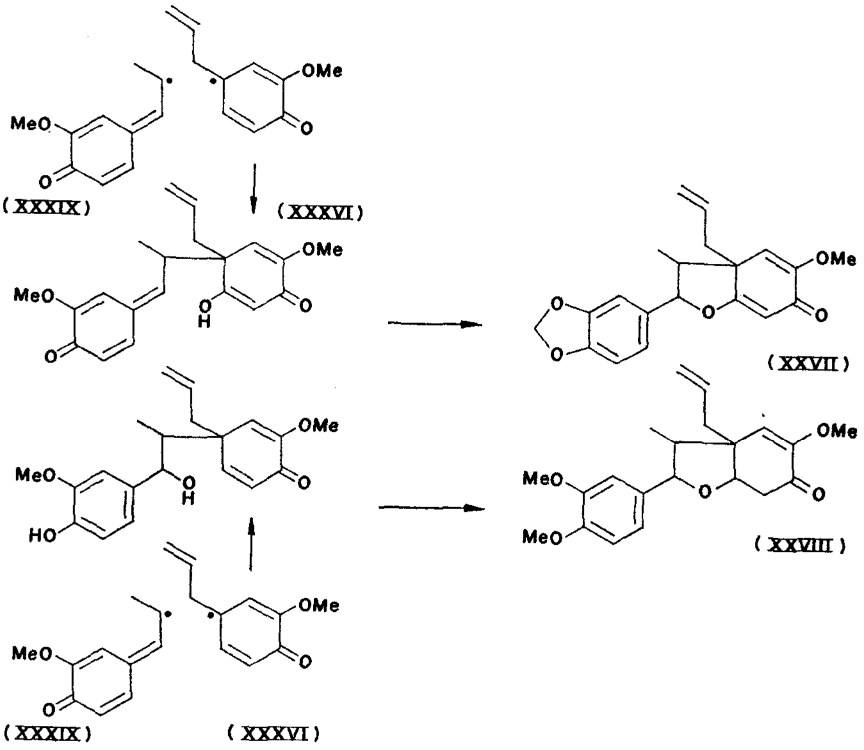
[68] Y. SUGI, *J. Pharm. Soc. Japan* **50,** 23 (1930); H. ERDTMAN and J. RUNENBERG, *Acta Chem. Scand.* **11,** 1060 (1957); J. RUNENBERG, *Acta Chem. Scand.* **12,** 188 (1958).

[69] A. OGISO, M. KURABAYASHI, H. MISHIMA and M. C. WOODS, *Tetrahedron Letters* 2003 (1968); M. C. WOODS, I. MIURA, A. OGISO, M. KURABAYASHI and H. MISHIMA, *Tetrahedron Letters* 2009 (1968).

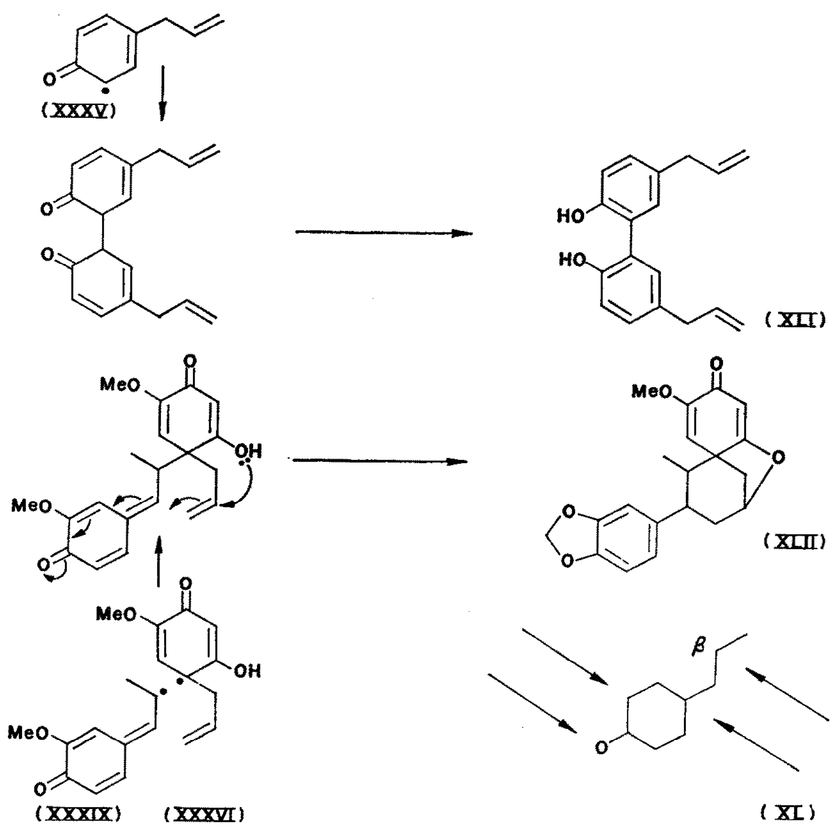
[70] H. ERDTMAN, *Biochem. Z.* **258,** 177 (1933); *Liebig's Ann. Chem.* **503,** 283 (1933).



Scheme 6A. Possible biosynthetic routes to neolignans.



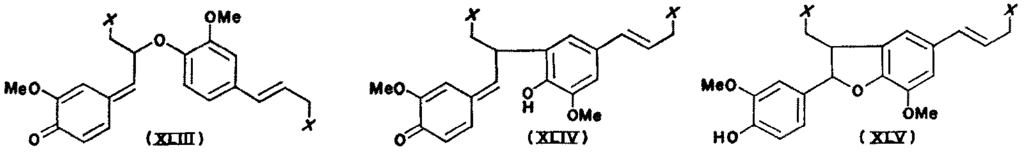
Scheme 6B. Possible biosynthetic routes to neolignans.



SCHEME 6C. POSSIBLE BIOSYNTHETIC ROUTES TO NEOLIGNANS.

of lignin-like structures. To Erdtman, the most important step in lignin biosynthesis seemed to be the addition of the phenolic hydroxyl group to the quinone methide moiety in XLIV. All this shows of course remarkable intuition, since at the time the only confirmation of this hypothesis was found in the structure of dehydrodiisoeugenol (XLV, $X = \mathrm{H}$), a synthetic oxidation product of isoeugenol.

With respect to their constitution, the neolignans are close relatives (Scheme 8) of the 2,3-dihydrobenzofurans obtusafuran (XLVI)[71] and melanoxin (XLVII)[72] which occur



SCHEME 7. THE QUINONE METHIDE INTERMEDIATES IN LIGNIN BIOSYNTHESIS FORMULATED BY ERDTMAN.

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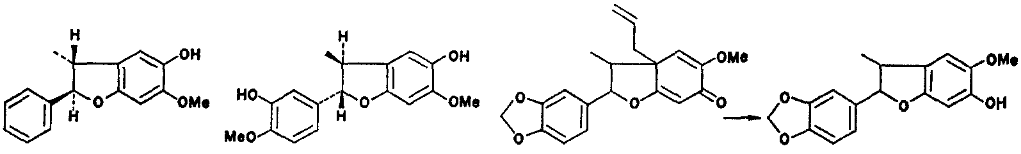
[71] M. GREGSON, W. D. OLLIS, B. T. REDMAN, I. O. SUTHERLAND and H. H. DIETRICHS, *Chem. Commun.* 1394 (1968).

[72] B. J. DONNELLY, D. M. X. DONNELLY, A. M. O'SULLIVAN and J. P. PRENDERGAST, *Tetrahedron* **25**, 4409 (1969).

TABLE 2. FREQUENCY OF ARYLPROPANOID

Sub family	Tribe	Genus	Total No. Spec.*
Lauroideae	Cinnamomeae		
	Cinnamomineae	*Cinnamomum*	22
		Dicypellium	1
		Ocotea	6
		Sassafras	1
		Umbellularia	1
	Anibineae	*Aniba*	1
		Licaria	2
	Cryptocaryeae		
	Eusideroxylineae	*Eusideroxylon*	1

* Total number of species in which identified arylpropanoids were located.



(XLVI) (XLVII) (XXVII) (XLVIII)

SCHEME 8. THE CONSTITUTIONAL RELATIONSHIP OF THE 2,3-DIHYDROBENZOFURANS EX *Dalbergia* SPECIES AND THE NEOLIGNANS.

respectively in *Dalbergia obtusa* Lecomte and *D. melanoxylon* Guill. et Perr. (Leguminosae–Papilionatae), together with neoflavanoids (e.g. L, LI) and cinnamylphenols (LII, LIII).[2] The biogenesis of these three classes of compounds is considered to involve a phenolic, acetate derived, C_6-unit and a cinnamyl C_9-precursor, according to a generalized diarylpropanoid biosynthetic pathway (Scheme 9).[73] The discovery of the neolignans now points to an alternative route, based wholly on cinnamyl C_9-precursors. In support of this hypothesis, the transformation XXVII → XLVIII is relevant. It was achieved through catalytic hydrogenation of burchellin (XXVII),[65] conditions which could have their equivalent in the living cell.

Two additional arguments have to be brought up in connection with this problem. As seen above, bis-arylpropanoids arise as the result of dimerization in a $C_6.C_3$-precursor. Thus, it is not surprising to find that the two C_6-rings of lignans (Scheme 3 B) and neolignans (Scheme 3C) are nearly always identically substituted. While melanoxin (XLVII) shows indeed the required identical catechol type oxygenation pattern of both aromatic rings, obtusafuran (XLVI) and with it the vast majority of its cogeneric neoflavanoids (e.g. L, LI) and cinnamylphenols (LII, LIII),[74] have two differently substituted rings. This fact is easier reconciled with a mixed, shikimate and acetate, biosynthesis for these compounds.

Furthermore, as we shall see shortly, the Lauraceae are at the bottom of the evolutionary

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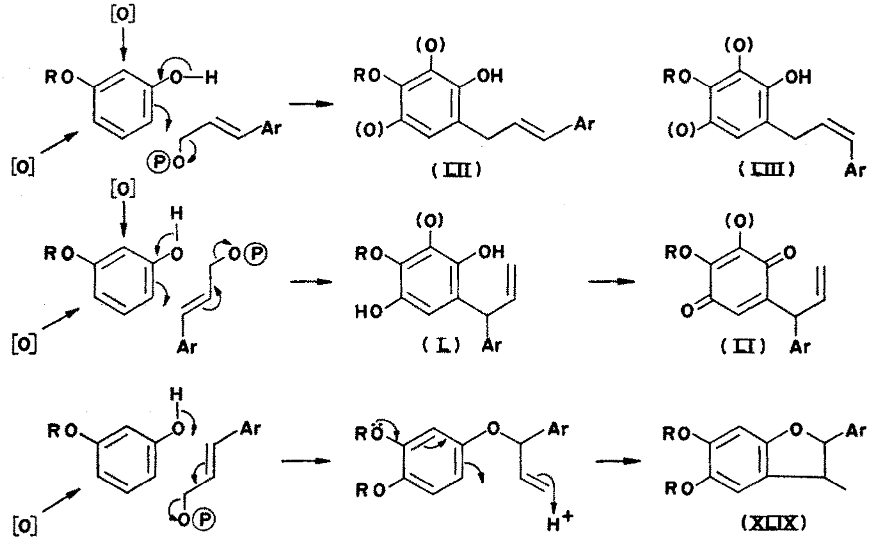
[73] W. D. OLLIS and O. R. GOTTLIEB, *Chem. Commun.* 1396 (1968).

[74] W. D. OLLIS, in *Recent Advances of Phytochemistry* (edited by T. J. MABRY, R. E. ALSTON and V. C. RUNECKLES), Vol. 1, p. 329, Appleton–Century–Crofts, New York (1968); O. R. GOTTLIEB, S. MAGESWARAN, W. D. OLLIS, R. J. ROBERTS and I. O. SUTHERLAND, *Anais Acad. Brasil. Ciênc.* **42**, Supplement 417 (1970).

CONTAINING LAURACEAE SPECIES

Cinnamyl ald.	Cinnamyl alc.	Safrole	Allyl Prop. benzenes	Lignans	Neolign.	Ref.
7	2	16	14			6, 59, 76, 77
			1			
		3	2	2	1	6, 60, 61, 66, 76, 78–80
		1	1			76
		1	1			6, 76
		4	1		2	6, 81, 82, 94
		1	1		1	64, 83
					1	63



SCHEME 9. PROPOSED BIOGENETIC CORRELATION BETWEEN *Dalbergia* CONSTITUENTS.

ladder concerning flavanoid biosynthesis, a domain in which the Leguminosae show such surprising versatility. Thus, after all, it does seem more reasonable to consider the 2,3-dihydrofurans (XLIX) and their cogeners (L–LIII) ex Leguminosae as linked to diarylpropanoid (flavanoid) rather than to bis-arylpropanoid (lignan) biosynthesis.

[75] R. HEGNAUER, *Chemotaxonomie der Pflanzen*, Vol. I, II, III, V, Birkhäuser Verlag, Basel (1962–1968).

[76] E. GUENTHER, *The Essential Oils*, p. 183, Van Nostrand, New York (1950).

[77] H. Y. TSAI, C. C. OU, C. K. TING, S. L. NIEH, *Chem. Abs.* **62**, 6337, 11623 (1965).

[78] (a) W. B. MORS, M. TAVEIRA MAGALHÃES and O. R. GOTTLIEB, *Perf. Essent. Oil Record* **50**, 26 (1959);. (b) O. R. GOTTLIEB and M. TAVEIRA MAGALHÃES, *Perf. Essent. Oil Record* **51**, 18 (1960); (c) O. R. GOTTLIEB, M. FINEBERG and M. TAVEIRA MAGALHÃES, *Perf. Essent. Oil Record*, **53**, 219 and 299 (1962).

[79] O. R. GOTTLIEB, *Perf. Essent. Oil Record* **48**, 386 (1957).

[80] G. A. FESTER, J. A. RETAMAR and A. I. A. RICCIARDI, *Chem. Abs.* **55**, 21251 (1961).

[81] O. R. GOTTLIEB and M. TAVEIRA MAGALHÃES, *Perf. Essent. Oil Record* **51**, 69 (1960).

[82] M. V. VON BÜLOW, O. R. GOTTLIEB and A. I. DA ROCHA, unpublished work.

[83] A. P. SEABRA, E. C. GUIMARÃES and W. B. MORS, *Anais Assoc. Brasil. Quim.* **26**, 73 (1967).

While bis-arylpropanoids, e.g. lignans, are widely distributed among Tracheophyta, they are already well represented in the gymnosperms. With the Magnoliidae they seem to attain a reasonable variety of constitution, as well as frequency of appearance, re-occurring afterwards only sporadically in the more highly evolved angiosperms (Scheme 3, notes).

Safrole (XX) is a constituent of the allylbenzene fraction of most Lauraceae species implicitly included in Table 2. Exceptions to this regularity are found only in the small, cinnamic aldehyde containing section of *Cinnamomum*,[59] and in *Aniba*, a genus whose quite distinctive chemistry will be considered below. This massive occurrence of safrole is all the more impressive, as seemingly only a few plant families other than the Lauraceae contain this metabolite. The ability to effect oxidative conversion of an *ortho*-hydroxy-methoxy- to a methylenedioxy-benzenoid system,[59] which was already implicitly suggested above upon consideration of lignan (Scheme 5) and neolignan (Scheme 6) biosynthesis, is shared by a limited number of plant families. These lie on the direct evolutionary line Magnoliidae—Rosales (Rosaceae, Leguminosae)—Sapindales (Rutaceae)—Umbellales (Umbelliferae).[84] In safrole producing species, this ability has, evidently, to be coincident with the presence of eugenol. This double requirement of raw material and reaction pathway makes safrole, in spite of its simple chemical structure, a good chemotaxonomic marker.

Co-existence of benzyltetrahydroisoquinoline derived alkaloids and of arylpropanoids in related plant taxa may be a manifestation of homology. Both classes of natural products issue from the same biogenetic route with bifurcation at the phenylalanine stage, and may use identical enzyme systems for phenol oxidative coupling. In the Lauraceae, considering the presently accepted system of classification, this phenomenon appears to occur on the

TABLE 3. OCCURRENCE OF $C_6.C_2N$- AND $C_6.C_3$-METABOLITES IN TWO FAMILIES OF THE MAGNOLIIDAE*

Family	Tribe	Genus	Benzyl-isoqui-nolines	Nitro-Phenan-threnes	Allyl ben-zones	Lig-nans
Aristolochiaceae						
	Sarumeae	*Heterotropa*			+	
		Asiasarum			+	
		Asarum			+	+
	Bragantieae	*Apoma*	+	+		
	Aristolochieae	*Aristolochia*	+	+		
Berberidaceae						
Berberidoidae	Nandineae	*Nandina*	+			
	Mahonieae	*Berberis*	+			
		Mahonia	+			
	Epimedieae	*Caulophyllum*	+			
		Leontice	+			
		Epimedium	+			
Podophylloideae	Podophylleae	*Podophyllum*				+
		Diphylleia				+

* For the original lit. see Ref. 75, Vol. III.

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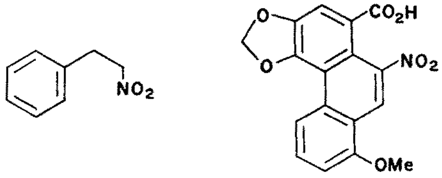
[84] N. W. Simmonds and R. Stevens, *Nature, Lond.* **187**, 752 (1956).

specific, as well as on the generic level. Although the chemistry of the family has not yet been sufficiently explored to allow its use as a chemotaxonomic guide, I feel, nevertheless, that the possibility exists: In at least two other families of the Magnoliidae a distinction between plants containing $C_6.C_2N$- or $C_6.C_3$-metabolites can be made on the tribal level (Table 3). At present, I am unable to understand the significance of this phenomenon, unless what is involved, at least to some extent, is form, not function.

NITRO-DERIVATIVES

Another metabolite whose origin clearly goes back to phenylalanine, is 1-nitro-2-phenylethane (LIV). This occurs, together with allylbenzenes, in *Aniba canelilla* (H.B.K.) Mez and in a physiological form of *Ocotea pretiosa* (Nees) Mez.[85]



(LIV) (LV)

SCHEME 10. NITRO-DERIVATIVES OF THE LAURACEAE (LIV) AND THE ARISTOLOCHIACEAE (LV).

In spite of its close association to phenylalanine, an ubiquitous precursor, nitrophenylethane seems to be a fairly rare natural compound. So far only one additional source has been disclosed: the fruits of *Dennettia tripetala* G. Baker,[86] Annonaceae which, as the Lauraceae, belongs to the order Magnoliales. The direct evolutionary relationship between the Magnoliales and the Piperales on one hand, and the Magnoliales and the Aristolochiales on the other, has been postulated. While I propose to comment on the chemical affinity of the preceding pair of orders at a later stage, it seems relevant here to call attention again (see also Table 3) to the nitro-derivatives (e.g. LV) of *Aristolochia* species.[87] These, however, seem to originate through the oxidation of aporphine type alkaloids (III) and, thus, unlike nitrophenylethane,[88] to be only indirect oxidation products of aminoacids. The role of aminoacids in the biogenesis of nitroderivatives has been established by direct experimentation for the case of the nitropropionic acid in *Penicillium atrovenetum* G. Smith.[89]

BENZOYL ESTERS

Benzyl benzoate (LVI) and benzyl salicylate (LVII), though rather widespread in flowers,[90] are certainly exceptional as constituents of healthy wood. This makes it all the more surprising that these esters do occur in very substantial amounts in the wood of most of the

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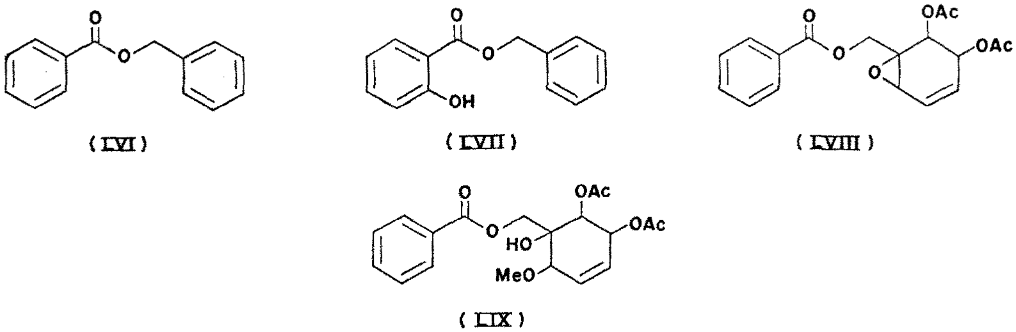
[85] O. R. GOTTLIEB and M. TAVEIRA MAGALHÃES, *J. Org. Chem.* **24**, 2070 (1959).
[86] J. I. OKOGUN and D. E. U. EKONG, *Chem. & Ind.* 1272 (1969).
[87] M. PAILER, *Fortsch. Chem. Org. Nat.* **18**, 55 (1960).
[88] O. R. GOTTLIEB, M. TAVEIRA MAGALHÃES and W. B. MORS, *Anais Acad. Brasil. Ciênc.* **33**, 301 (1961).
[89] A. J. BIRCH, B. J. MCLOUGHLIN, H. SMITH and J. WINTER, *Chem. & Ind.* 840 (1960).
[90] Y. R. NAVES and G. MAZUYER, *Natural Perfume Materials*, p. 138, Reinhold, New York (1947).

TABLE 4. THE OCCURRENCE OF BENZOYL ESTERS IN LAURACEAE SPECIES

	Benzyl Benzoate	 Salicylate	Ref.
Cinnamomum			
zeylanicum Blume	+		6, 76
Ocotea			
teleiandra (Meissn.) Mez	+	+	91
Aniba			
burchellii Kosterm.	+		65
firmula (Nees et Mart.) Mez	+	+	92
fragrans Ducke	+		40
gardneri (Meissn.) Mez	+	+	93
guianensis Aubl.	+	+	94
parviflora (Meissn.) Mez	+		95
permollis (Nees) Mez	+	+	82

Aniba species so far examined (Table 4). And again, the wood of *Ocotea teleiandra* (Meissn.) Mez also contains benzyl benzoate and benzyl salicylate,[91] in complete opposition to all other species of this genus which have been analysed for steam volatile components. In some native forms of cinnamon, *Cinnamomum zeylanicum* Blume, a substantial part of eugenol is displaced by benzyl benzoate in the leaves.[6,76]

The chemical relationship of the Lauraceae and Annonaceae families, which has already been mentioned in connection with alkaloids (Scheme 1, notes) and nitrophenylethane (LIV), is also apparent in connection with benzoic acid esters (Scheme 11), and may help to understand the biosynthesis of senepoxyde (LVIII) and seneol (LIX) which occur in the fruit of *Uvaria catocarpa*.[96]



SCHEME 11. BENZOYL ESTERS OF THE LAURACEAE (LVI, LVII) AND THE ANNONACEAE (LVIII, LIX).

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[91] Y. R. NAVES, O. R. GOTTLIEB and M. TAVEIRA MAGALHÃES, *Helv. Chim. Acta* **44**, 1121 (1961).

[92] O. R. GOTTLIEB and M. TAVEIRA MAGALHÃES, *Perf. Essent. Oil Record* **50**, 119 (1959).

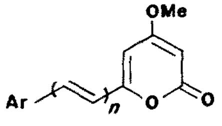
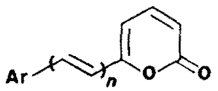
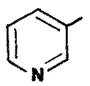
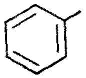
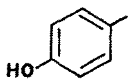
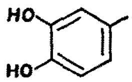
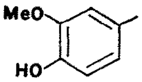
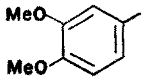
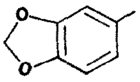
[93] M. V. VON BÜLOW and O. R. GOTTLIEB, *Anais Acad. Brasil. Ciênc.* **40**, 299 (1968).

[94] M. V. VON BÜLOW and O. R. GOTTLIEB, unpublished work.

[95] M. TAVEIRA MAGALHÃES and O. R. GOTTLIEB, unpublished work.

[96] R. HOLLANDS, D. BECHER, A. GAUDEMER, J. POLONSKY and N. RICROCH, *Tetrahedron*, **24**, 1633 (1968)

Table 5. Distribution of 2-pyrones in *Aniba* species[38–40,98–103] (The numbers refer to phylogenetic types (see Fig. 4)).

Ar	 $n = 0$	$n = 1$	 $n = 0$	$n = 1$
	*duckei* 1 *fragrans* 1 *rosaeodora* 1 *coto* 2a			
	*duckei* 1 *fragrans* 1 *gardneri* 1 *heringerii* 1	*firmula* 1 *gardneri* 1 *heringerii* 1 *permollis* 2a	*coto* 2a *pseudocoto* 2a	*parviflora* 2a
				*parviflora* 2a
				*parviflora* 2a
				*parviflora* 2a
		*firmula* 1 *canelilla* 2a *permollis* 2a		
	*duckei* 1 *firmula* 1 *fragrans* 1 *gardneri* 1 *rosaeodora* 1 *parviflora* 2a *permollis* 2a	*heringerii* 1 *permollis* 2a	*coto* 2a *pseudocoto* 2a	*parviflora* 2a

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[98] O. R. Gottlieb, A. M. Bittencourt, W. B. Mors and M. Taveira Magalhães, *Anais Acad. Brasil. Ciênc*, **36**, 29 (1964); A. M. Bittencourt, O. R. Gottlieb, S, Mageswaran, W. B. Mors, W. D. Ollis, I. O. Sutherland and M. Taveira Magalhães, *Tetrahedron* **27**, 1043 (1971).

[99] C. M. andrade da Mata Rezende, M. V. von Bülow, O. R. Gottlieb and S. Lamêgo Vieira Pinho, *Anais Acad. Brasil. Ciênc.* **43**, 121 (1971).

[100] C. M. Andrade da Mata Rezende, M. V. von Bülow, O. R. Gottlieb, S. Lamego Vieira Pinho and A. I. da Rocha, *Phytochem.* **10**, 3167 (1971).

[101] O. R. Gottlieb and W. B. Mors, *J. Org. Chem.* **24**, 17 (1959).

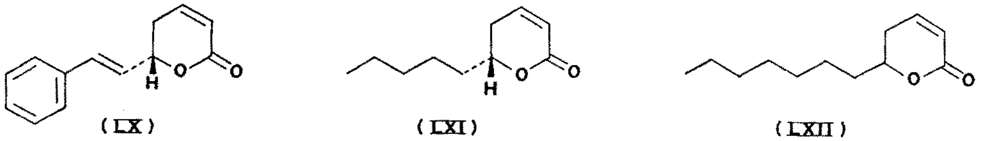
[102] O. R. Gottlieb, M. Taveira Magalhães and W. B. Mors, *Anais Assoc. Brasil. Quim.* **18**, 37 (1959).

[103] W. B. Mors, M. Taveira Magalhães, O. Araujo Lima, A. M. Bittencourt and O. R. Gottlieb, *Anais Assoc. Brasil. Quim.* **21**, 7 (1962).

2-PYRONES

Brazilian botanists claim great difficulties in the characterization of the genus *Aniba*. Distinction from other genera, e.g. *Ocotea*, can often be made only by examining the flowers. Brazilian chemists do not experience any difficulty of this sort. Practically every *Aniba* species so far investigated yielded aromatic derivatives of monocyclic 2-pyrones.[97] This statement has to be qualified only with respect to *A. burchellii* Kosterm. and *A. guianensis* Aubl. from which no such compounds have yet been isolated. This, of course, does not mean that they are definitely absent. They may be minor constituents, accompanying much larger quantities of the neolignans burchellin (XXVII)[65] and guianin ($C_{18}H_{17}O_2 . O_2CH_2 . OCH_3$).[94]

The *Aniba*-pyrones are distributed among four general types (Table 5). These are associated with either an aryl or a styryl substituent at position 6 and the presence or absence of a methoxyl group at position 4. Prior to attempt an evaluation of these data, it is imperative to refer to the occurrence of related 2-pyronic metabolites in other plant taxa. Within the Lauraceae, aromatic 2-pyrones have been found additionally in one instance. *Cryptocarya caloneura* Scheff. contains 6-styryl-5*S*-5,6-dihydro-2-pyrone (LX) (Scheme 12).[104]


(LX) (LXI) (LXII)

SCHEME 12. 2-PYRONES OF *Cryptocarya* SPECIES.

Significantly (in relation to what has been stated above), the same compound (LXIII) (Scheme 13) occurs also in a species of the Annonaceae,[105] another family of the order Magnoliales. It was already mentioned that the Magnoliales are supposed to have evolved into the Piperales, and it is exciting to find, crammed solely into two closely related species of the genus *Piper*, three well represented types of aromatic 2-pyrones (LXV–LXVII).[97,106,107] It has equally been said that the Magnoliidae are supposed to have evolved directly into the Rosales. And indeed, in what appears so far to be the only excursion into evolutionary more advanced territory, a 2-pyrone, mundulea lactone (LXIV), was isolated from *Mundulea sericea* (Leguminosae, of the Rosales, subclass Rosidae).[108] If, in contradistinction, we turn now to examine organisms which are more primitive than the Magnoliidae, we will find psilotin (LXVIII) in *Psilotum nudum* (L.) Griseb.[109,110] and *Tmesipteris tannensis* Berh.[110] Significantly, these species belong to the two living genera of Psilopsida, the Silurian-Devonian ancestors of the terrestrial tracheophytes. Even the fungi *Polyporus hispidus*[111] and *P. schweinitzii*[112] contain a 2-pyrone, hispidin (LXIX), considered to be a precursor of a fungus 'lignin'.[111]

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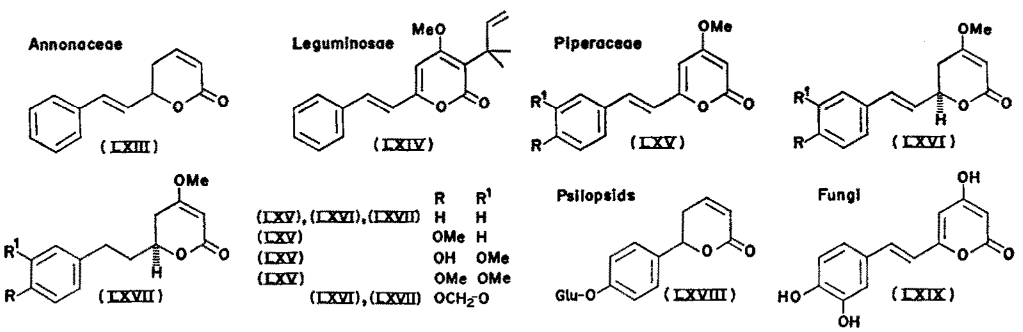
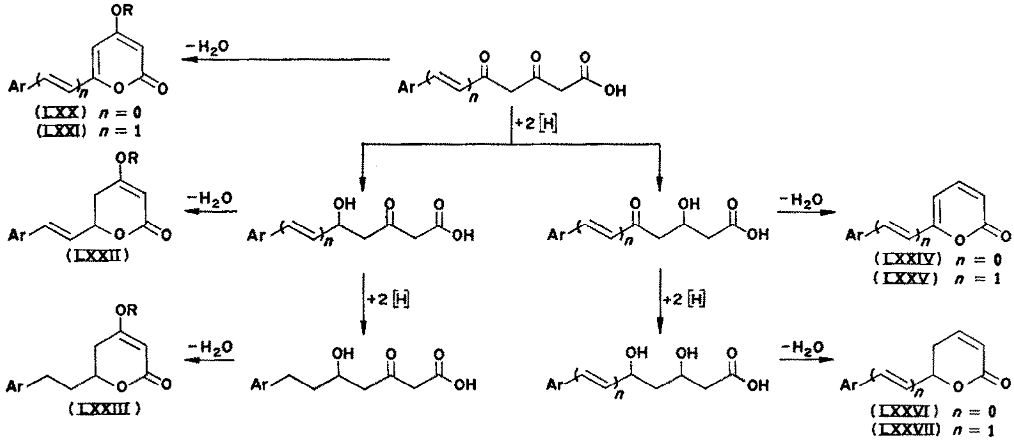
[97] W. B. Mors, M. Taveira Magalhães and O. R. Gottlieb, *Fortsch. Chem. Org. Nat.* **20**, 132 (1962).
[104] J. R. Hlububueek and A. V. Robertson, *Austral. J. Chem.* **20**, 2199 (1967).
[105] K. Jewers, Tropical Products Institute, London, private communication to W. B. Mors (Oct. 1969).
[106] H. Sauer and R. Hänsel, *Planta Med.* **15**, 443 (1967).
[107] G. Snatzke and R. Hänsel, *Tetrahedron Letters* 1797 (1968).
[108] M. C. Manger, W. D. Ollis and I. O. Sutherland, *Chem. Commun.* 577 (1967).
[109] A. G. McInnes, S. Yochida and G. H. N. Towers, *Tetrahedron* **21**, 2939 (1965).
[110] A. Tse and G. H. N. Towers, *Phytochem.* **6**, 149 (1967).
[111] J. D. Bu'Lock, P. R. Leeming and H. G. Smith, *J. Chem. Soc.* 2085 (1962).



SCHEME 13. 2-PYRONES OF: SPECIES OF THE INDICATED TAXA.

All the hitherto mentioned pyrones belong to five classes derivable by the polyketide route[113] involving initiation either by benzoic acids, leading to 6-aryl derivatives, or by cinnamic acids, leading to 6-styryl or 6-dihydrostyryl derivatives. One way to rationalize this biosynthetic concept is formally shown in a unified form in Scheme 14. Alternative, though less general, pathways are clearly possible. These involve not only initiation by cinnamic acid where benzoic acid was postulated, but even initiation by acetic acid. For instance, it is possible to conceive the formation at least of psilotin (LXVIII) exclusively from acetic acid. The existence of massoilactone (LXI)[114] and of 5,6-dihydro-6-heptyl-2-pyrone (LXII)[115] in *Cryptocarya massoia* (Becc.) Kosterm. would seem to corroborate such a view.



SCHEME 14. POSSIBLE BIOSYNTHETIC DERIVATION OF 2-PYRONES.

Representatives of the indicated constitutional types occur in the following genera: (LXX) *Aniba*; (LXXI) *Polyporus, Aniba, Piper, Mundulea*; (LXXII) *Piper*; (LXXIII) *Piper*; (LXXIV) *Aniba*; (LXXV) *Aniba*; (LXXVI) *Psilotum, Tmesipteris*; (LXXVII) *Cryptocarya*, and a genus of the Annonaceae.

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[112] A. UENO, S. FUKUSHIMA, Y. SAIKI and T. HARADA, *Chem. Pharm. Bull.* **12**, 376 (1964).

[113] A. J. BIRCH and F. W. DONOVAN, *Austral. J. Chem.* **6**, 360 (1953); A. J. BIRCH, *International Congress of Pure and Applied Chemistry*, p. 73, Butterworths, London (1960).

[114] L. CROMBIE and P. A. FIRTH, *J. Chem. Soc.* **C**, 2852 (1968).

[115] G. W. K. CAVILL, D. V. CLARK and F. B. WHITFIELD, *Austral. J. Chem.* **21**, 2819 (1968).

TABLE 6. FREQUENCY OF FLAVANOID

Sub family	Tribe	Genus	Total No. Spec.*
Lauroideae	Perseae		
	Perseineae	*Persea*	2
		Machilus	1
	Beilschmiediineae	*Apollonias*	1
		Beilschmiedia	3
	Cinnamomeae		
	Cinnamomineae	*Cinnamomum*	1
		Ocotea	1
		Nectandra	1
		Umbellularia	1
	Anibineae	*Aniba*	1
	Litseeae		
	Litseineae	*Litsea*	2
		Neolitsea	1
	Laurineae	*Laurus*	2
		Lindera	3
	Cryptocaryeae		
	Cryptocaryineae	*Cryptocarya*	1
Cassythoideae		*Cassytha*	1

* Total number of species in which identified flavanoids were located. (LXXVIII) Chalcone: rubranine (see Scheme 15). (LXXIX) Flavanone: pinocembrin (see Scheme 15). (LXXX) Dihydroflavonols: taxifolin astilbine. (LXXXI) Flavonols: kaempferol and kaempferol-3-rhamnoside, quercetin and quercetin-3-rhamnoside, azaleatin. (LXXXII) Flavan-3, 4-diol: leucocyanidin. (LXXXIII) Flavan-3-ol: (±) -catechin. (LXXXIV) Anthocyanin: paeonin. (LXXXV) Flavones (see Scheme 16). (LXXXVI) *a*, Linderone; *b*, methyllinderone (see Scheme 16).

As an attractive feature of the proposed scheme (Scheme 14), however, the pyrone type (LXX), formed by the least number of reactions, is indeed most widely distributed. Additional pathways are as usual more specific and lead to types LXXII and LXXIII in *Piper*, to types LXXIV and LXXV in *Aniba* and to type LXXVII in *Cryptocarya.*

Let us now come back to the *Aniba* pyrones. As represented in Scheme 14, the absence of a 4-methoxyl substituent in types LXXIV and LXXV may well be caused by a reductive deoxygenation at the polyketide stage. It is attractive to assign to those species which are capable of effecting this additional biosynthetic step a particular position, most probably a more recent origin, in the evolutionary history of the genus.

In order to verify the validity of this assumption on conventional morphological grounds, a comparative analysis of the floral verticils of the known species of *Aniba* was undertaken.[1] This was based on the classical phylogenetic concept of gradual reduction and suppression of whorls in the evolution from primitive to the more recent forms. Since in *Aniba* perigonium and gynaecium show practically no variability, observations were based on the

CONTAINING LAURACEAE SPECIES

LXXVIII	LXXIX	LXXX	LXXXI	LXXXII	LXXXIII	LXXXIV	LXXXV	LXXXVI	Ref.
			1	1	1				119, 120
		1	1		1				121, 122
			1	1					119
			1	2					123, 124
			1	1					119
		1							125
						1			126
			1						119
1	1								116, 117
		1	1	1					123, 127
			1						128
			2	2					119
			1	1			1	1	119, 129, 130
			1						119
				1					123

androecium. In Fig. 4 it is shown how in *Aniba* the androecium, starting from a primitive type 1 with three fertile and one sterile verticils, developed through two parallel suppressive and reductive routes (types 2a and 2b) to type 3, with only two fertile and one sterile verticils. If the *Aniba* species, which have hitherto been examined chemically, are classified according to these evolutionary types and the structure of their pyrones (Table 5), it becomes indeed clear that the morphological and chemical criteria support each other.

We have noted previously that *A. burchellii* and *A. guianensis* occupy chemically a rather special position within the genus. Not surprisingly, both these species belong to the relatively more highly evolved type 2a.

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[119] E. C. BATE-SMITH, *J. Linn. Soc. London* (*Botany*) **58**, 95 (1962).
[120] T. A. GEISSMAN and H. F. K. DITTMAR, *Phytochem.* **4**, 359 (1965).
[121] T. KONDO, H. ITŌ and M. SUDA, *J. Agric. Chem. Soc. Japan* **30**, 717 (1956).
[122] T. KONDO, H. ITŌ and M. SUDA, *Chem. Abs.* **52**, 12395 (1958).
[123] R. C. CAMBIE *et al.*, *New Zealand J. Sci.* **4**, 604 (1961).
[124] J. B. HARBORNE and J. MENDEZ, *Phytochem.* **8**, 763 (1969).
[125] F. E. KING, T. J. KING and D. W. RUSTIDGE, J. *Chem. Soc.* 1192 (1962).
[126] K. HAYASHI, *Acta phytochim., Tokyo* **13**, 19 (1943).
[127] K. HAYASHI, *Chem. Abs.* **48**, 5942 (1954).
[128] T. NAKABAYASHI, *J. Agric. Chem. Soc. Japan* **27**, 469 (1953).

FLAVANOIDS AND BENZOPHENONES

Both 2-pyrones and flavanoids employ the shikimate-prephenate and acetate-malonate pathways. But while with the Magnoliidae *Aniba* and *Piper* these 2-pyrones seem to have reached the maximum level of secondary constitutional variation, the few flavanoids which have been located in these genera reveal the closest possible association with their non-aromatic precursors. Thus, in *Piper methysticum* Forster and *P. spec.* Womersley, chalcones (and possibly flavanones) accompany the 2-pyrones.[106] Only two flavanoids have been hitherto located in *Aniba* species. These are again a chalcone, rubranine (LXXVIII)[116] and a flavanone, pinocembrin (LXXIX),[117] which both occur in the wood of *Aniba rosaeodora* Ducke.

Besides chalcones and flavanones, flavonols and leucoanthocyanidins are also considered to be primitive chemical characters in the evolutionary scale of flavanoids in plants.[118] Indeed, the flavanoids of the Lauraceae (Table 6) are represented mostly by common members of these classes.

Replacement of flavonols by flavones, as well as 6- or 8-hydroxylation, however, are considered to be an indication of an advanced character in the evolutionary history of flavanoids,[118] So far, such more highly evolved flavanoids (LXXXV) have been located only in *Lindera lucida* Boerl.[129] *Lindera pipericarpa* Benth. contains two compounds of unusual constitution, linderon (LXXXVI(a)) and methyllinderon (LXXXVI(b)).[130] Comparison with the cogeneric flavone LXXXV(c) suggests that they may be modified chalcones.

Aniba rosaeodora wood contains a high proportion of linalool, a fact which may be considered significant in connection with the geranyl attachment to the phloroglucinol moiety of rubranine (LXXVIII). Indeed, the genus *Aniba* is best known as the source of rosewood, whose commercial value stems from its linalool content.[76] The distribution of this monoterpene in *Aniba* seems, nevertheless, to be rather restricted. Additionally to *A. rosaeodora*, only *A. duckei* Kosterm. contains substantial amounts in its wood, bark and leaves.[131] These two species are morphologically and chemically very close relatives (see also Table 5). Their only conspicuous difference lies in the presence of cotoin (LXXXVII) in *A. duckei*, as opposed to pinocembrin (LXXIX) in *A. rosaeodora* (Scheme 15).[117] It is fascinating to consider that benzophenones and chalcones are vinylougues (Table 7), exactly as the pairs of 2-pyrones in the *Aniba*-types LXX/LXXI and LXXIV/LXXV, a fact which leads to similar commentaries concerning their biosynthesis (Scheme 17).

Cotoin and other benzophenones have been isolated additionally from two further *Aniba* species (Table 7).[117] Outside the Lauraceae, this class of compounds occurs in widely scattered plant taxa and, thus, seems to present an example of parallelism. Let us note. nevertheless, 4-hydroxybenzophenone from *Talauma mexicana*,[133] a species belonging to the most ancient of the angiosperm families, the Magnoliaceae.

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[116] G. COMBES, P. VASSORT and P. F. WINTERNITZ, *Tetrahedron* **26**, 5981 (1970); W. M. BANDARANAYAKE, L. CROMBIE and D. A. WHITING, *J. Chem. Soc.* **6**, 804 (1971).

[117] O. R. GOTTLIEB and W. B. MORS, *J. Am. Chem. Soc.* **80**, 2263 (1958).

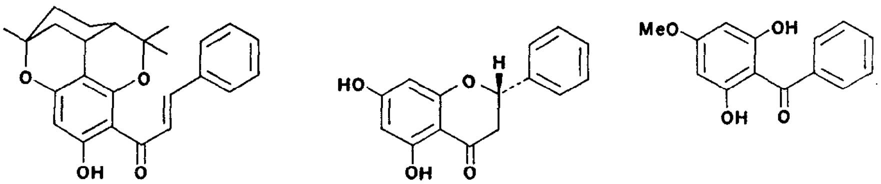
[118] J. B. HARBORNE, in *Comparative Phytochemistry* (edited by T. SWAIN), p. 271, Academic Press, London (1966).

[129] H. H. LEE and C. H. TAN, *J. Chem. Soc.* 2743 (1965).

[130] A. K. KIANG, H. H. LEE and K. Y. SIM, *J. Chem. Soc.* 4338 (1962).

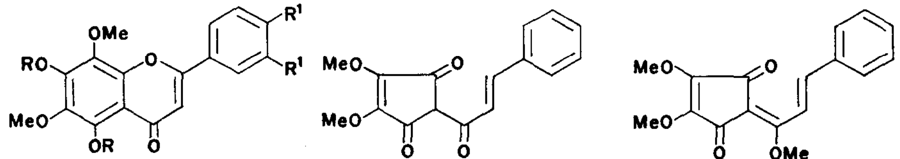
[131] O. R. GOTTLIEB, M. FINEBERG, M. LIMA GUIMARÃES, M. TAVEIRA MAGALHÃES and N. MARAVALHAS, *Perf. Essent. Oil Record* **55**, 253 (1964).

[133] E. S. PALLARES and H. M. GARZA, *Chem. Abs.* **42**, 2730 (1948).



(LXXVIII) (LXXIX) (LXXXVII)

SCHEME 15. CONSTITUENTS OF *Aniba rosaeodora* (LXXVIII, LXXIX) AND *A. duckei* (LXXXVII).

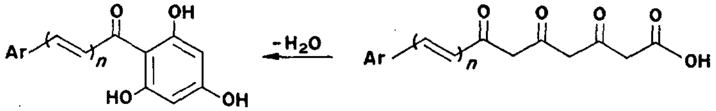


	R	R¹	R¹
(LXXXV) a	H	OCH_2O	
b	Me	OCH_2O	
c	Me	H	H

(LXXXVI) a

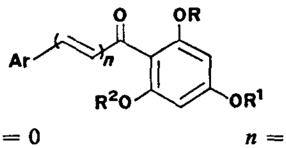
(LXXXVI) b

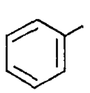
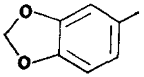
SCHEME 16. FLAVANOIDS OF *Lindera lucida* (LXXXV) AND *L. pipericarpa* (LXXXVI).



SCHEME 17. POSSIBLE BIOSYNTHETIC DERIVATION OF CHALCONES ($n = 1$) AND BENZOPHENONES ($n = 0$) IN *Aniba*.

TABLE 7. DISTRIBUTION OF BENZOPHENONES ($n = 0$) AND THE CHALCONE ($n = 1$) PRECURSOR OF PINOCEMBRIN IN *Aniba* SPECIES[117]



Ar	$n = 0$	$n = 1$
	*duckei* $R=R^2=H, R^1=Me$	*rosaeodora* $R=R^1=R^2=H$
	coto $R=R^2=H, R^1=Me$	
	pseudocoto $R=H, R^1=R^2=Me$ $R=R^1=R^2=Me$	
	*pseudocoto* $R=H, R^1=R^2=Me$ $R=R^1=R^2=Me$	

For other natural benzophenones see MAGNOLIIDAE: Magnoliales (Magnoliaceae). HAMAMELIDAE: Urticales (Moraceae). DILLENIIDAE: Theales (Guttiferae). ROSIDAE: Rosales (Leguminosae), Myrtales (Myrtaceae), Rhamnales (Rhamnaceae). COMMELINIDAE: Zingiberales (Zingiberaceae).[132]

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[132] O. R. GOTTLIEB, *Phytochem.* 7, 411 (1968).

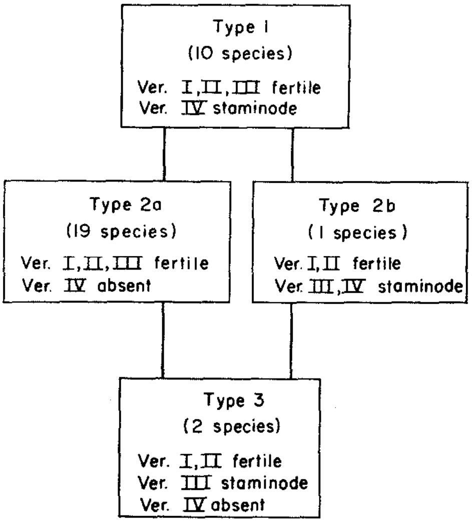


FIG. 4. PHYLOGENETIC DEVELOPMENT OF THE GENUS *Aniba*, BASED ON THE REDUCTION AND SUPRESSION OF VERTICILS IN THE ANDROECIUM.

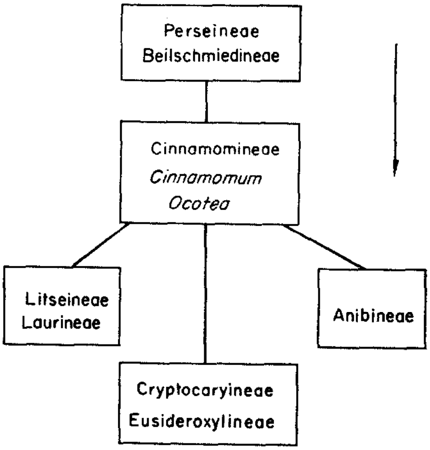
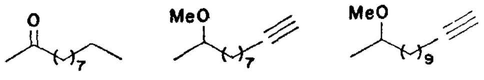


FIG. 5. MORPHOLOGICAL RELATIONSHIPS AMONG THE SUBTRIBES OF THE LAURACEAE.

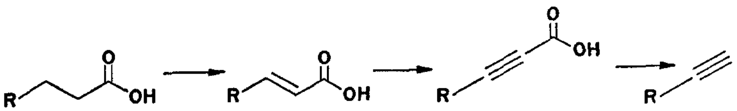
FATTY ACIDS AND TERMINAL ALKENE-ALKYNE PAIRS

Lauric acid appears in high proportion in the seeds of several species belonging to the genus *Litsea* (as well as to the genera *Actinodaphne*, *Cinnamomum*, *Laurus*, *Lindera*, *Neolitsea*, *Sassafras* and *Umbellularia*).[6] Oil distilled from the leaves of *Litsea odorifera* Val. contains chiefly methylnonylketone (LXXXVIII), while the bark contains 2-methoxyundec-10-yne (LXXXIX).[134] It is clearly most reasonable to consider the generation of both these compounds linked to the biosynthesis of lauric acid.[135] Scheme 19 represents Bu'Lock's suggestion concerning the shortening of the fatty carbon-chain and the appearence of a terminal ethynyl group.[135] The compound LXXXIX, together with a companion substance of probable constitution XC,[134] were the first acetylenes to be isolated from the Lauraceae family. In the light of present knowledge, it is probable that the corresponding olefinic compounds also occur in *Litsea odorifera* and a re-examination of this species would be desirable.



(LXXXVIII) (LXXXIX) (XC)

SCHEME 18. C-11 AND C-13 CONSTITUENTS OF *Litsea odorifera*.



SCHEME 19. POSSIBLE BIOSYNTHETIC ROUTE TO A TERMINAL ACETYLENE GROUP, ACCORDING TO BU'LOCK.

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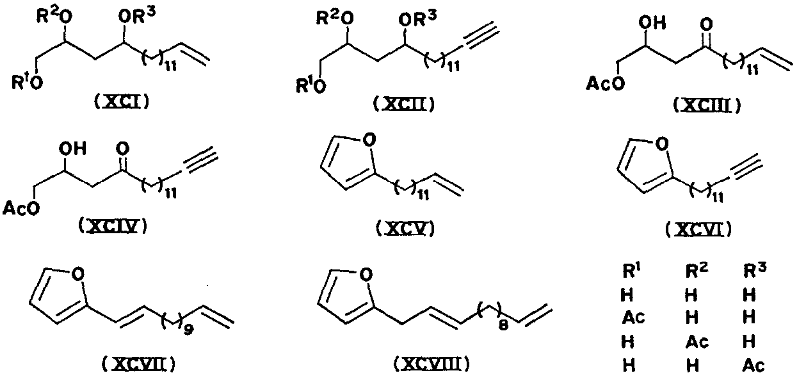
[134] W. S. MATHEWS, G. B. PICKERING and A. T. UMOH, *Chem. & Ind.* 122 (1963).

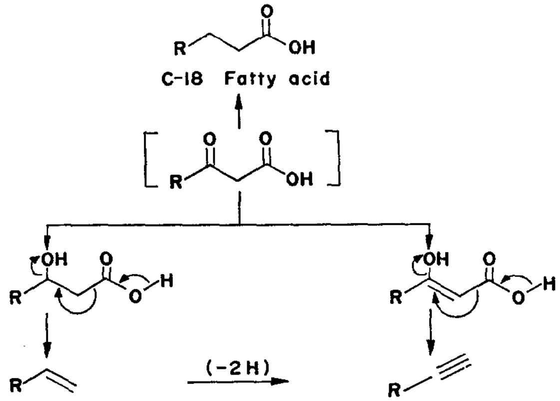
[135] J. D. BU'LOCK, in *Comparative Phytochemistry* (edited by T. SWAIN), p. 79, Academic Press, London (1966).

The presence of substantial amounts of fatty oil in Lauraceae seeds is by no means a general character of the family. Many fruits accumulate oils in the pericarp.[6] In opposition to seed fats, the pericarp fats contain only minor proportions of lauric acid, while oleic acid predominates vastly. Thus, the pericarp of avocado fruit, *Persea americana* Miller, contains 40–80 % oil of the following fatty acid composition: oleic acid 47–81 %, linoleic acid 6–17 %, palmitic acid 7–25 %.[136] The seed contains only 1–2 % fatty matter. An additional 1–2 % is constituted by 14 substances (XCI–XCVIII),[137] 12 forming pairs which differ constitutionally only with respect to the terminal alkene or alkyne bond.[138] Again, it was considered that the routes to the avocatins may be variants upon the pathways associated with the biosynthesis of long chain fatty acids (Schemes 21 and 22), with the particularity that here, not surprisingly, connection to C-18 fatty acid metabolism had to be claimed.[137]



R¹	R²	R³
H	H	H
Ac	H	H
H	Ac	H
H	H	Ac

SCHEME 20. C-17 CONSTITUENTS OF *Persea americana*.



SCHEME 21. POSSIBLE BIOSYNTHETIC DERIVATION OF THE TERMINAL ETHYLENE AND ACETYLENE GROUPS OF THE AVOCATINS AND THE RUBRENOLIDES.

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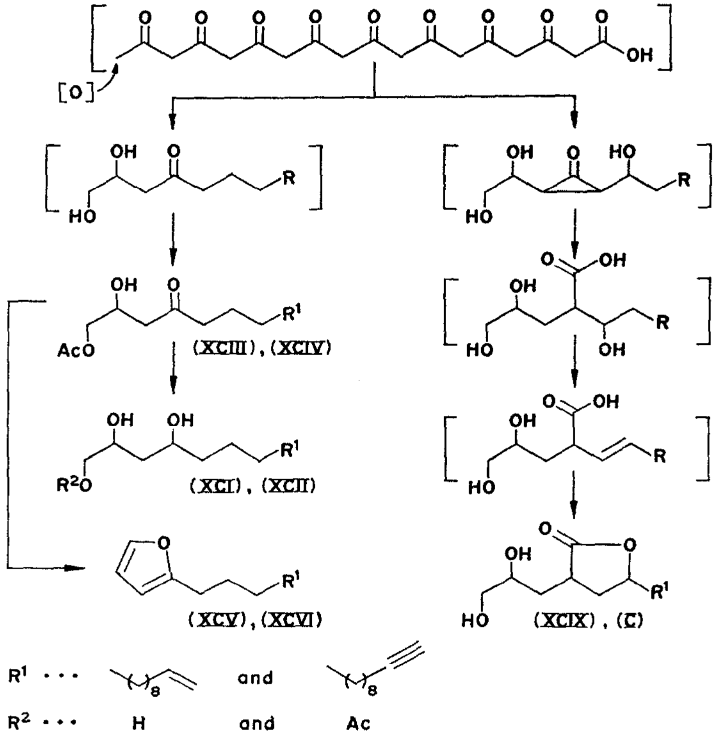
[136] T. P. HILDITCH and P. N. WILLIAMS, *The Chemical Constitution of Natural Fats*, 4th edn, p. 191, Chapman-Hall, London (1964).

[137] H. MAGALHÃES ALVES, D. T. COXON, C. P. FALSHAW, W. O. GODFREDSEN and W. D. OLLIS, *Anais Acad. Brasil. Ciênc.* **42**, Suppl. 45 (1970).

[138] Y. KASHMAN, I. NÉEMAN and A. LIFSHITZ, *Tetrahedron* **25**, 4617 (1969); *ibid.* **26**, 1943 (1970).



SCHEME 22. POSSIBLE BIOSYNTHETIC DERIVATION OF THE OXYGENATED TERMINALS OF THE AVOCATINS (XCI–XCVI) AND THE RUBRENOLIDES (XCIX,C)

An additional alkene-alkyne pair was isolated recently as an equimolecular mixture of rubrenolide (XCIX) and rubrynolide (C) from the wood of *Nectandra rubra* (Mez) C. K. Allen.[139] Several constitutional features of these compounds establish their relationship to all previously mentioned alkene and alkyne constituents of Lauraceae. Clearly then, their formation should involve analogous biosynthetic principles. The only difficulty concerning this proposal is the fact that the carbon skeleton of rubrenolide and rubrynolide shows a ramification. Now, this may of course indicate that the construction of their molecules proceeds through the coupling of two precursors formed by independent routes. In other words, the oxygenated terminals of the constituents of *Nectandra rubra*, and by inference of *Persea americana*, may not derive by the polyketide pathway. In view, however, of all the previously mentioned clues which associate the Lauraceae alkenes and alkynes to fatty acids of corresponding chain length, the views summarized in Scheme 22 are presently favoured. The extrusion of a C-atom from a normal polyketide precursor is rationalized through a Favorsky type rearrangement. Alternatively, oxidation of the appropriate di-enol group could lead to a diradical prone to suffer electron pairing to the intermediate cyclopropanone. Such a diradical coupling process would be identical in mechanistic form with that involved in the diradical coupling of phenols. Finally, introduction of the γ-lactone may involve addition of the carboxyl thus generated to a double bond, whose formation at the specific site would be assisted by the conjugated carbonyl of the original polyketomethylene chain.[140]

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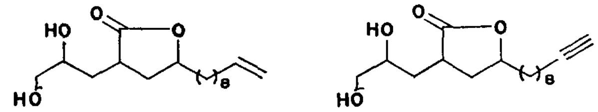
[139] N. CAVALCANTI FRANCA, D. T. COXON, O. R. GOTTLIEB and W. D. OLLIS, *Anais Acad. Brasil. Ciênc.* **43**, 123 (1971).

[140] O. R. GOTTLIEB and W. D. OLLIS, unpublished work.

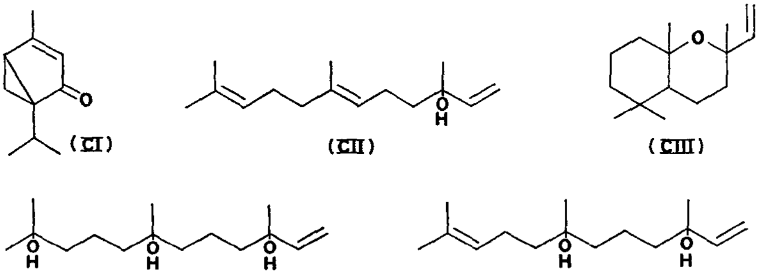


(XCIX) (C)

Scheme 23. C-17 constituents of *Nectandra rubra*.

MONO- AND SESQUITERPENES

Monoterpenes are widely distributed and were reported for species of *Cinnamomum* (especially camphor, linalool, cineol),[6,76] *Nectandra* (esp. pinene),[141] *Umbellularia* (esp. umbellulone, CI),[76] *Aniba* (esp. linalool, see above),[76] *Litsea* (esp. citral, cineol),[6] *Laurus* (esp. cineol),[6] *Lindera* (esp. linalool, citral, geraniol, borneol),[6] *Cryptocarya* (esp. linalool).[142] Sesquiterpenes, which co-occur in minor amounts in most instances, appear as principal constituents in several *Persea* species (esp. caryophyllene)[143] and in *Ocotea caparrapi* (Nates) Dugand [nerolidol (CII) and derivatives (CIII–CV)].[144] *Lindera strychnifolia* Vill.,[145] *Neolitsea aciculata*,[146] *N. sericea* (Blume) Koidz.[146] and *N. zeylanica* Merr.[147] contain furanosesquiterpenes (Scheme 25). Some of these incorporate the cyclopropane ring of linderen (CVI), also obvious in umbellulone (CI), while in others, e.g. deoxysericealactone (CVIII), the furan ring may have been oxidatively transformed. All are based on the biogenetically interrelated germacrane—eudesmane skeleta.[148] The occurrence of such compounds in Lauraceae is not wholly exceptional. The germacranolides costunolide (ex *Talauma mexicana* Don),[149] parthenolide



(CI) (CII) (CIII)

(CIV) (CV)

Scheme 24. Selected mono- and sesquiterpenes of *Umbellularia* (CI) and *Ocotea* (CII–CV) species.

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[141] N. Botafogo Gonçalves, *Arch. Pharm.* **271**, 461 (1933); Y. R. Naves, *Perf. Essent. Oil Record* **43**, 38 and 987 (1952).

[142] Y. R. Naves, H. Magalhães Alves, V. H. arndt, O. R. Gottlieb and M. Taveira Magalhães, *Helv. Chim. Acta* **46**, 1056 (1963).

[143] R. W. Scora, B. O. Bergh, W. B. Storey and J. Kumamoto, *Phytochem.* **9**, 2502 (1970).

[144] J. Borges del Castillo, C. J. W. Brooks and M. M. Campbell, *Tetrahedron Letters* 3731 (1966); C. J. W. Brooks and M. M. Campbell, *Phytochem.* **8**, 215 (1969).

[145] H. Ishii, M. Nakamura, T. Tozyo and K. Takeda, *Phytochem.* **9**, 2189 (1970); H. Tada, H. Minato and K. Takeda, *J. Chem. Soc.* **C**, 1070 (1971), and previous parts of the series.

[146] K. Takeda, J. Horibe, M. Teraoka and H. Minato, *J. Chem. Soc.* **C**, 973, 1547 (1970).

[147] B. S. Joshi, V. N. Kamat and T. R. Govindachari, *Tetrahedron* **23**, 973 (1967).

[148] W. Herz, in *Recent Advances in Phytochemistry*, (edited by T. J. Mabry, R. A. Alston and V. C. Runeckles), Vol. 1, p. 229, Appleton–Century–Crofts, New York (1968).

[149] O. Collera, F. Walls, F. Garcia, S. E. Flores and J. Herran, *Bol. Inst. Quim. Univ. Nacl. Auton. Mex.* **15**, 38 (1963); *Chem. Abs.* **61**, 9769 (1964).

TABLE 8. DISTRIBUTION OF CLASSES OF

Sub family	Tribe	Subtribe	Genus
Lauroideae	Perseae	Perseineae	*Persea* = *Machilus* = *Nothaphoebe* = *Alseodaphne* *Phoebe*
		Beilschmiediineae	*Apollonias* *Beilschmiedia* *Dehaasia* *Endiandra* *Hexapora* *Mezilaurus* *Potameia* = *Syndiclis*
	Cinnamomeae	Cinnamomineae	*Actinodaphne* *Cinnamomum* = *Parthenoxylon* *Dicypellium* *Ocotea* = *Nectandra* = *Pleurothyrium* *Sassafras* *Umbellularia*
		Anibineae	*Aiouea* *Aniba* *Endlicheria* *Licaria* = *Acrodiclidium* = *Misanteca* *Phyllostemodaphne* *Systemonodaphne* *Urbanodendron*
	Litseeae	Litseineae	*Litsea* = *Tetranthera* *Neolitsea* = *Tetradenia*
		Laurineae	*Laurus* *Lindera* = *Iteadaphne*
	Cryptocaryeae	Eusideroxylineae	*Eusideroxylon*
		Cryptocaryineae	*Cryptocarya* *Ravensara*
	Hypodaphneae		*Hypodaphnis*
Cassythoideae			*Cassytha*

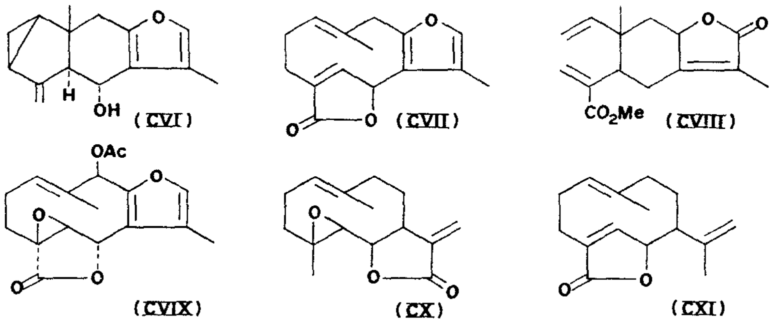
* According to Kostermans.[3]

† Approximate number of species for which a chemically significant analysis of at least one organ is reported.

COMPOUNDS IN LAURACEAE GENERA

No. species known*	exam.†	A	B	C	D	E	F	G	H	I	J	K
339	2						+			+	+	
	9	+					+					
	2	+										
	1	+										
174	2	+										
2	1						+					
⩾200	4	+					+					
<33	2	+										
~80	0											
1	0											
9	0											
21	0											
60–70	3	+							+			
<341	23	+	+		+		+		+		+	
2	1		+									
⩽449	14	+	+	+	+		+					+
⩽248	3	+					+			+	+	
2	1		+						+			
1	1		+				+		+		+	
30	0											
40	15		+	+	+	+	+	+			+	
~40	0											
~45	2		+									
1	0											
2	0											
1	0											
~400	23	+					+		+	+	+	
~80	6	+					+		+			+
2	2	+					+		+		+	
~100	9	+					+		+		+	+
2	1		+									
>200	11	+				+	+				+	
18	0											
1	0											
20	6	+					+					

A—Alkaloids, excepting pseudoalkaloids; B—Arylpropanoids, excepting the ubiquitous cinnamoyl derivatives; C—Nitrophenylethane; D—Benzoyl esters; E—2-Pyrones; F—Flavanoids; G—Benzophenones; H—Lauric acid; I—Alkenes-Alkynes; J—Monoterpenes; K—Sesquiterpenes.



Scheme 25. Selected sesquiterpenes of *Lindera* (CVI, CVII) and *Neolitsea* (CVIII, CIX) species.

(CX, ex *Michelia champaca*)[150] and aristolactone (CXI, ex *Aristolochia serpentaria* L. and *A. reticulata* Nutt.)[151] were located in the Magnoliidae.

Germacranolides and eudesmanolides are typical constituents of the Compositae, a family which is also well known as the source of a host of furanosesquiterpenes, even if these are not based on an eudesmane, but an eremophyllane skeleton.[152] The Compositae (Asterales, subclass Asteridae) and the Lauraceae are phylogenetically nearly as far apart as two families can be within the dicotyledons. Here, the appearance of identical or similar chemical characters must, consequently, be considered a manifestation of convergence, rather than relationship.

CONCLUSIONS

Prerequisites to valid chemosystematic comments are a representative knowledge of the distribution of individual compounds in the family[8] and an assessment of the sequences of reaction steps by which individual compounds arise from simple ubiquitous precursors.[135] With respect to the Lauraceae, while we are clearly far away from the first of these goals (see Table 8, relation of morphologically and chemically examined species), all biosynthetic schemes are based on comparative phytochemistry. These limitations place the following conclusions on a provisional, tentative basis.

From the static viewpoint, Kostermans' system of classification of Lauraceae genera[3] seems 'natural' enough (Table 8). Among the two subfamilies, the Cassythoideae, represented by herbaceous, parasitic vines, seem to be void of arylpropanoids. With respect to their alkaloid chemistry, they approach the genus *Cryptocarya*, a relationship which holds equally on morphological grounds. Within the arboreous Lauroideae, arylpropanoids seem to concentrate in the tribe Cinnamomeae. None have yet been found in the Perseae, which are characterized by the presence of simple benzyltetrahydroisoquinoline alkaloids. The Litseeae stand apart on account of their sesquiterpene chemistry, and their surprisingly complex flavanoids, while the Cryptocaryeae distinguish themselves as producers of a relatively more varied gamut of alkaloidal types.

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[150] T. R. Govindachari, B. S. Joshi and V. Kamat, *Tetrahedron* **21**, 1509 (1965).

[151] M. Martin-Smith, P. de Mayo, S. J. Smith, J. B. Stenlake and W. D. Williams, *Tetrahedron Letters* 2391 (1964).

[152] V. Herout and F. Šorm, in *Perspectives in Phytochemistry* (edited by J. B. Harborne and T. Swain), p. 139, Academic Press, London (1969).

Kostermans[3] introduces his system of classification with the following statement: "The course of phylogenesis (of the Lauraceae) is not clear; the only thing we know is that the family must be rather old. I have refrained from trying to make a chronological family tree and have simply grouped related genera together. Even the position of the groups (tribus) has no proper phylogenetic base." This text is accompanied by a diagram (for a simplified version see Fig. 5), which contains an arrow. Clearly, this stresses the dynamic aspects of the author's morphological analysis, in spite of his verbal denial to any significance. In honour of the great botanist, this analysis, and with it the arrow, are, in general, in agreement with the chemical data.

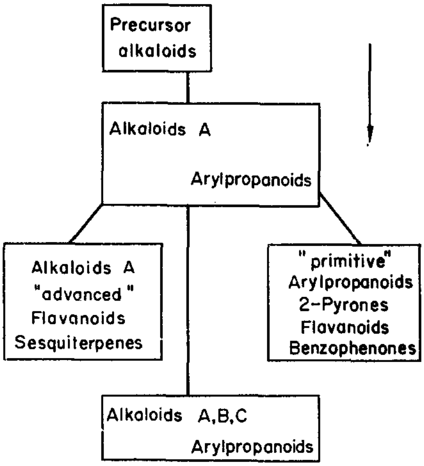

FIG. 6. CHEMICAL RELATIONSHIPS AMONG THE SUBTRIBES OF THE LAURACEAE, SUPERIMPOSED UPON THE SYSTEM OF FIG. 5. (p. 1562).

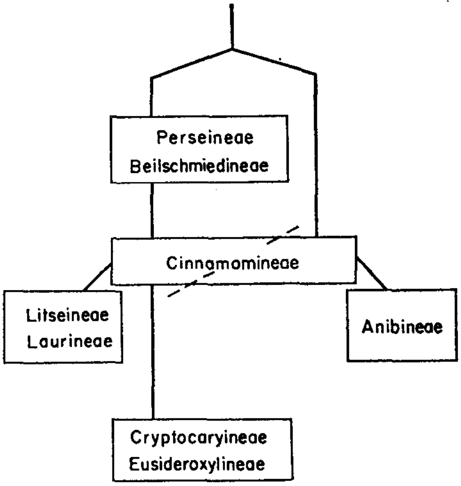

FIG. 7. TENTATIVE REPRESENTATION OF POSSIBLE EVOLUTIONARY AFFINITIES AMONG THE SUBTRIBES OF THE LAURACEAE.

Most of the Lauroideae subtribes lie on the alkaloid-trail Perseineae → Cryptocaryineae This leads gradually from the simple benzyltetrahydroisoquinoline precursors, through aporphines, to alkaloidal types which appear afterwards in the more advanced Ranunculales and Papaverales (but not in the Piperales or Aristolochiales). Somewhere at the aporphine stage of this route, a bifurcation occurs to the Litseineae which appear as a climax taxon due to the presence of special and possibly advanced flavanoids and sesquiterpenoids. According to the original diagram, this bifurcation occurs at the *Ocotea* genus of the Cinnamomineae. This subtribe harbours presently a very great number of species and for its major genera, *Cinnamomum* and *Ocotea*, a considerable number of chemical varieties or forms have been described.[6,59,76,78] Morphological differences, even among genera, are slight, and to this date the validity of several genera is disputed. Not surprisingly, classification of individual species has proved exceedingly difficult. In the Cinnamomineae, both arylpropanoids and alkaloids are found in the same genus, if rarely in the same species. Thus it may be inferred from morphological and chemical evidence that the Cinnamomineae continue to show considerable evolutionary vigour. Would it be possible to separate from this pool a section in closer relationship to the Anibineae? This subtribe, relatively restricted geographically and poor in existing species, has a conspicuously different chemistry, centered around 'primitive' flavanoids, aryl and styryl 2-pyrones, benzophenones, benzoyl esters and arylpropanoids. In opposition to the Cryptocaryineae, the Anibineae seem to lie towards the end of an evolutionary side branch. One cannot fail to notice that their chemical composition brings them closer to the more primitive magnoliaceous cluster of the Magnoliales than indeed their proper lauraceous entourage.

The data are summarized in Fig. 6, where chemical characters are superimposed on Kostermans' map of subtribes. They lead to an, admittedly, tentative representation of evolutionary affinities (Fig. 7). If I summoned the courage to formulate the proposal at all, this was done in the hope that it may stimulate further research into the Lauraceae.

Acknowledgements—Research into the Lauraceae without a firm basis in a tropical region would be a near impossibility. I am deeply indebted not only to my colleagues at the Instituto Nacional de Pesquisas da Amazônia, Manaus, but also to the Director Dr. Paulo Almeida Machado, the botanists William Rodrigues and Arthur A. Loureiro, as well as the librarian Algenir Ferraz, for their decisive help in this work.

Key Word Index—Lauraceae; chemotaxonomy; arylpropanoids; alkaloids; flavanoids; terpenes.