PHYTOCHEMICAL EVOLUTION

Por *Otto Richard Gottlieb*[1]

PHYTOCHEMISTRY AND TERRESTRIAL PLANTS

The ultraviolet part of the solar radiation is capable of promoting not only the formation, but also the cleavage of chemical bonds. Hence the organic compounds of the prebiotic phase and the primordial organisms were viable only in aquatic medium, protected by the UV absorbing oxygen of H_2O, or in the internal cavites of hydrated clay, protected by the light excluding walls of the solid material, and the dry land remained sterile. Atmospheric oxygen led to the development of a stratospheric layer of ozone which, less than 1 billion years ago, had acquired sufficient thickness to shield the Earth from the major portion of the short-wave (< 300 nm) part of the solar spectrum. This was the time of separation into multicellular plants, fungi and animals, each of these kingdoms having developed a different defensive system against excess ultraviolet radiation. The permanent regeneration of burnt cells of the animal skin, for instance, does not operate in plants.

Chlorophytes constitute a major group of algae within which several evolutionary lines have led from unicellular forms to multicellular organisms. One of these lines encompasses the Charales which are considered ancestral to land plants (Melkonian 1982). However, the aqueous habitat confers protection against solar radiation to algae. Thus, about half a billion years ago, when invading humid environments of the land surface, possibly through primitive members of the bryophytes, the plant phylum must have solved the problem of the UV screen. Chemically Chlorophyta and Bryophyta have much in common. The photosynthetic systems of both divisions contain chlorophylls a and b, as well as carotenoids such as B-carotene and xanthophylls. Both store starch and possess cellulosic cell walls, characteristics which continue to prevail in all more recent plant groups. The possibility of a direct line from green algae to bryophytes, however, is not supported by steroid or triterpenoid data (Suire and Asakawa 1979). This would imply that the bryophytes should be more closely related to cormophytes from which they nevertheless differ by the presence of ent-sesquiterpenoids (Markham and Porter 1978). Such oligoterpenoids must have appeared independently, perhaps as allelochemics, in both groups, which thus seem to have evolved in parallel.

The most conspicuous chemical difference between aquatic protoctists and terrestrial plants refers to the exploitation of the shikimate pathway. In all forms of algae, this is limited to the production of phenylalanine and tyrosine, already incorporated in proteins since the primitive bacteria, and of derivatives of a few other pre-tyrosine molecules. Only with the bryophytes a post-tyrosine chemistry, based on cinnamic acid, is initiated. Deamination of aromatic amino acids to cinnamic acids may have occurred sporadically in other groups and certainly occurs in fungi. The special importance that cinnamoyl units acquired in Bryophyta, however, is possibly due to their activation by coenzyme A. Ployketides, compounds formed by the condensation of acetyl-CoA as starter unit and malonyl-CoA for chain extension, dominate the allelochemistry of aerobic bacteria and of algae. The substitution in this process of the starter unit by cinnamoyl-CoA in bryophytes led to flavones and flavonols. Flavonoids, such as chalcones, aurones, flavones and flavonols, absorb UV light and should act as photoscreens (McClure 1975) in Bryophyta and in all divisions of more modern terrestrial plants. To the light absorbing flavonoids also belong the anthocyanidins which, again present in the great majority of Plantae, supply an additional element of colour to the landscape.

Apart from UV radiation, there exist other phenomena in an aerial environment requiring

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[1] **Instituto de Química, Universidade de São Paulo, Caixa Postal 20780, 01498 São Paulo, SP, Brasil**

special adaptation of plant life: One concerns feeding pressure by animals, mainly insects, the other concerns properties of the air with its low density and humidity. It is again cinnamate chemistry that conditions the adaptation to these environmental challenges. Reductive deviation from the biosynthetic route leading to anthocyanidins results in catechins and protonated leucoanthocyanidins. Condensation of representatives belonging to the two latter classes of flavonoid compounds gives the so called condensed tannins, important general defense against virus, bacteria, fungi, insects and herbivores.

The aqueous habitat of algae does not only confer protection against solar radiation and insect predation, but also favours buoyancy and contact of all organs with water and nutrients, avoiding the difficulties inherent to growth on dry land: the possibility of suffocation and shading by a horizontal mass of organisms, and the necessity of conducting water and soluble nutrients to organs. Opposition to gravity and opening of tracheids and vessels require the acquisition of rigidity. Algae are flexible as a consequence of their chemical composition. Sugars and amino acids can only form flexible macromolecules since the monomers are linked through heteroatoms (oxygen in cellulose and in pectins, major cell wall components of algae and of land plants, nitrogen in protein) with nonbonding orbitals. Sugars and amino acids cannot be polymerized by linkage of C-C bonds and cross links which would impart rigidity. New pathways leading to UV absorbing compounds and to rigid polymers were required in land plants. It was first observed by Bate-Smith and Metcalfe (1957) that condensed tannins and lignins, the polymers which harden the cellulosic tissue of vascular plants, frequently occur together. Indeed, the syntheses of both materials require reductive power. Besides condensations (e.g. to flavonoids) reductions are also activated by the thiol ester function of cinnamoyl-CoA. The resulting cinnamyl alcohols polymerise oxidatively into lignins.

It is instructive to consider that the reductive sequences must be absent from mosses. Not only do these plants lack proanthocyanidins (Swain 1979), but the structure of the lignin-like compound which incrusts de cell walls of *Sphagnum* is based on a cinnamic acid (Tutchek 1975).

PHYTOCHEMISTRY AND PLANT DEFENSE

Organisms are subject to attack by predators and may produce allelochemicals for protection. Algae, for example, contain defensive polyketides and sesquiterpenoids. The former are generated by the condensation of acetate units, a process which leads primarily to fatty acids, and the latter are generated by the condensation of mevalonate units, a process which leads primarily to steroids. The products of the so called secondary metabolism, structurally very variable micromolecules supposedly with an ecological role, thus arise by extension of the primary routes to micro- and macromolecules of intrinsic value to their producer. Analogously, in ligneous plants the shikimate pathway is used not only in the synthesis of cinnamyl alcohols, precursors of the lignins the intrinsic value of which was examined above, but the evolutionary sequence continues with the transformation of post-tyrosine products into allelochemicals. This connection between intrinsic and ecological function (Gomes and Gottlieb 1978) has clear evolutionary connotations. Thus in the most ancient *surviving* tracheophytes, Lycopodiatae (lycopods) and Equisetatae (horsetails), in which lignification is absent or very slight, common secondary metabolites comprise, besides nicotin, the lysine + acetate derived Lycopodium alkaloids and mevalonate derived steroid saponins, respectively. The flavonoid theme in Lycopodiatae is expressed by flavones and biflavones (as in Gymnospermae) while in Equisetae mainly flavonols and only secondarily flavones abound. Here proanthocyanidins start to appear, while in Filicatae (ferns) 92% of all examined genera contain them (Swain 1979). Ferns also show considerable lignification. Their major and highly characteristic allelochemical groups nevertheless are acetate derived methylenebisphloroglucinols and mevalonate derived sesquiterpenoid indanones and triterpenoid ecdysons.

In conifers, presence of condensed tannins, detected in 74% of the examined genera, remains important and lignification of tissue attains its maximum. Mevalonate derived products, such as mono- and sesquiterpenoids in essential oils, diterpenoids in balsams and resins, and triterpenoids such as ecdysons, play an important allelochemical role. In addition, flavones, including biflavones and C-glycoflavones, relatively few flavonols (including myricetin) and stilbenes are widespread in conifers. Flavonoid formation preceded that of lignins evolutionarily, hence flavonoids have no direct connection with the woody habit, being simply characteristic of land plants. A direct link between lignification and secondary metabolism is established by the use of cinnamyl alcohols in lignin formation, but also by the synthesis of micromolecules, either through their oxidative transformation into lignans or through further reduction along the primary shikimate pathway to propenyland allylphenols. Gymnosperms thus attained a climax in the expansion of the shikimate pathway and one is entitoled to wonder why this broader synthetic capacity was so badly exploited for micromolecular variation. True, we have no chemical knowledge of now extinct but formerly so important gymnospermous groups as seed ferns, Nilssoniales and Benettitatae and can only extrapolate data for surviving taxa. Considering their vast geographical distribution, their long period of domination of the land flora

(Niklas et al 1983) or even only their considerable body size, the number of known secondary metabolites from gymnosperms is, relatively to angiosperms, exceedingly small. The probable reason for this chemical difference between gymnosperms and the equally highly lignified (with exception of the more advanced taxa) angiosperms will now be disscussed.

It is widely agreed that selection of secondary metabolites by, and coevolution with, phytophagous and pathogenic agents are the prime factors operational in shaping the diversity of natural products (Ehrlich and Raven 1965, Swain 1977, Rhoades 1979). However, the major defense mechanism in pteridophytes and gymnosperms is still unspecialized, based on lignins and condensed tannins which make plant tissue, carbohydrates and proteins, mechanically and enzymatically indigestible (Niklas, 1982). In contrast, defence in angiosperms evolved into a specialized one. Small amounts of toxic micromolecules gradually replaced condensed tannins, detected only in 54% of the examined genera, and lignins. The unspecialized defence of pteridophytes and gymnosperms is hardly breachable. In the case of the specialized defense in angiosperms, however, selection can lead to the introduction of detoxification mechanisms for action on particular micromolecules. Selection entails a shift first from one compound to another within the same biosynthetic group of secondary metabolites and, after exhaustion of the possibilities in this group, to anotner one (Cronquist 1977, Kubitzki and Gottlieb, 1984b). This replacement of general by specialized defence is exemplified by the positive relationship of diminishing lignosity and content of condensed tannins with benzylisoquinoline alkaloid diversity in the families belonging to the Magnoliiflorae Ranunculiflorae group of superorders (Gottlieb 1982).

So we may arrive at the postulate that the enormous diversity of angiospermous micromolecules is due to interaction with (as opposed to simple repulsion of) pathogens and herbivores. The result of the frequently mutualistic association of flowering plants mostly, but not exclusively, with insects was the explosion of natural products chemistry which conditioned both biological systems to dominate the Earth for the last 100 million years. Nevertheless, we did not yet discuss how this chemical diversification came to pass: was it haphazard or did it follow any recognizable trend? There is only one practical approach to an answer to this question, the inspection of the structures of the several tens of thousands of known natural compounds in relation to recognized morphologically homogeneous taxons, such as e.g. Dahlgren's (1980) superorders. The analysis of the data reveals micromolecules of flowering plants to be endowed with two dynamic characteristics: a broad range of oxidation-reduction levels and the derivation from all primary metabolites, including the initial, intermediate and final ones, of the shikimate pathway.

OXIDATION LEVELS OF ANGIOSPERMOUS MICROMOLECULES

Secondary metabolites such as flavonoids, lignoids, polyketides, terpenoids and steroids, as well as alkaloids, which are found in gymnosperms may also occur in angiosperms, were they are frequently accompanied by more highly oxidized, and occasionally by less highly oxidized, derivatives of the same biogenetic group. This observation was quantified for flavonoids (Gottlieb et al 1982). Averaging the data for the oxidation patterns of all known flavonoids, both the triketide and the cinnamate derived moieties appear at conspicuously lower oxidation states for gymnospermous than for angiospermous compounds. Practically all known flavonoids of pteridophytes and gymnosperms have 5,7-dioxygenated A-rings, suggesting the direct condensation of a cinnamate unit with the triketide chain to have taken place. The presence of additional oxy-groups, introduced by oxidation at carbons 6, 8 or both, is common only in angiosperms (and in Bryophyta). The cinnamate unit of flavonoids in pteridophytes and gymnosperms is predominantly oxygenated at 4' and to a progressively lesser extent at 3', 4' and at 3', 4', 5'. The analogous unit in angiosperms is commonly oxygenated at 3', 4' and to a progressively lesser extent at 4' and at 3', 4', 5'. The well known high relative contribution of coniferyl (4-hydroxy-3-methoxycinnamyl) alcohol versus sinapyl (4-hydroxy-3, 5-dimethoxycinnamyl) alcohol in the synthesis of fern and conifer versus flowering plant lignins (Sarkanen and Ludwig 1971) is viewed as further evidence for the higher oxidation level in angiosperms with respect to cinnamate derived moieties. The lignins of some presumably advanced gymnosperm genera (*Tetraclinis* and *Podocarpus*) and of some primitive angiosperm genera (*Belliolum* and *Zygogynum*) show intermediate compositions. Among the Gnetatae, the lignin compositions of *Welwitschia* and *Gnetum* are closer respectively to gymnosperms and angiosperms (Gottlieb and Kubitzki 1984). Moreover, lignans from gymnosperms stem commonly from dioxycinnamyl alcohol, while in the angiosperms lignans and neolignans are frequently derived from trioxycinnamyl alcohols as well.

In regard to polyketides, accumulation of highly oxidized derivatives (e. g. polyacetylenes) is restricted to angiosperms. Terpenoids and steroids as highly oxidized as the monoterpenoid iridoids, the sesquiterpenoid lactones, the diterpenoid tanshinones, royleanones and coleones, the triterpenoid cucurbitacins and limonoids and the steroidal withaferins are all known only from the angiosperms. The formation of indole (tryptophane-monoterpenoid) alkaloids as well as benzylisoquinoline alkaloids involves oxidative steps and is also restricted to the angiosperms. The transformation of the ubiquitous protein amino acids into cyanogenic glycosides also requires oxidative steps. Thus it is not surprising that the cyanogens of pteridophytes and gymnosperms should derive only from phenylalanine and tyrosine respectively (Hegnauer 1977), while the cyanogens of angiosperms derive additionally from several other precursors such as valine, isoleucine and leucine.

There can be little doubt that the origin of the angiosperms coincided with a substantial amplification of the oxidation-reduction potential of enzymatic catalysts for the formation of micromolecules and/or with the development of enzymatic catalysts for the transference of regiospecific protection devices, e.g. by O-methylation of hydroxyls or imine-formation of carbonyls. But what about the angiosperms themselves? Does the origin of new evolutionary lines within this plant division follow the same trend? Indeed, this seems to be the case for taxa of higher hierarchic levels, i.e. superorders, possibly also orders and sometimes even families. Some cases of positive correlations of the mean oxidation level of compounds belonging to different biogenetic groups and Sporne's (1980) evolutionary advancement indices of the angiosperm families (or the mean indices for the families of and order or superorder) in which they occur have been reported (Gottlieb, 1984).

The existence of a positive correlation between oxidation levels of compounds and evolutionary advancement of the taxa which produce them means that, just as for the origin of the angiosperms themselves, the radiation of each major subgroup coincided with an abrupt amplification of the oxidation level of the compounds of one of its, usually highly diversified, biosynthetic groups of secondary metabolites. A clear understanding of the evolutionary polarity of micromolecular oxidation states for taxa of lower hierarchic levels is yet less well documented. The line between "higher" and "lower" levels is of course not always easy to draw and will vary from taxon to taxon. However, correlations for some micromolecular groups with evolutionary considerations based on morphological evidence for genera or species does indicate the reversal of the trend, i.e. within each taxon or evolutionary line evolutionary diminution of the oxidation level may occur.

In conclusion, increasing oxidation of micromolecules constitutes the general trend which is most pronounced at the onset of each major phyletic line of angiosperms. It is opposed by a reductive trend within each of these lines. These observations can be tentatively rationalized considering pressure of herbivory (Kubitzki and Gottlieb 1984b).

DERIVATION OF ANGIOSPERMOUS MICROMOLECULES

Amplification of the oxidation-reduction potential, however, is not the only cause for diversity of secondary metabolites in angiosperms. In order to understand the phenomenon more fully it is necessary to remember also the best known of the evolutionary trends, the gradual substitution of woody forms by herbaceous ones which operates in several lineages. Reduced utilization for the production of lignins and condensed tannins should cause initially the surplus of cinnamate, raw material for the biosynthesis of allelochemics of primitive angiosperms. The continuing decrease in the importance of the shikimate pathway and the connection between primary and secondary metabolism requires that the transition from woody to herbaceous angiosperms be accompanied in the long run by a curtailment of shikimate precursors for the biosynthesis of allelochemics. Let us look now into the evidence for these postulates.

The basic concept (Kubitzki and Gottlieb 1984a) that the deepest disjunction in the angiosperms does not lie between the monocots and the dicots was pioneered on chemical grounds (presence/absence of gallo- and ellagitannins) by Bate-Smith (1972, 1973) and forcefully driven home on morphological grounds by Huber (1977, 1982). Three evidences indicate the magnolialean block to preserve the characteristics of the extinct ancestor of the angiosperms more faithfully than the rosiflorean block (Gottlieb 1984). This does of course not mean that present day magnolialean families are more archaic than modern rosiflorean families. Indeed, the opposite could be true as well, since many of the latter families continue to show unspecialized defense through tannins. One evidence refers to the general defense of the primitive representatives of the magnolialean block: lignins and condensed tannins, just as in all possible ancestral tracheophytes. A novel type of defense material, gallo-and ellagitannins was introduced later on with the primitive representatives of the rosiflorean block. The second evidence refers to the fact that the typical micromolecular classes of the magnolialean block, such as neolignans, tyrosine derived alkaloids and cyanogens, as well as pyrones are general characters, commonly reappearing here and there in the rosiflorean block. Inversely, the typical micromolecular classes of the rosiflorean block, gallic acid derivatives (BateSmith 1972), phenylalanine derived cyanogens (Hegnauer 1977), anthranilate derived alkaloids, iridoids, indole alkaloids, tropane alkaloids, pyrrolizidine alkaloids, glucosinolates, limonoids etc., do not occur or do so extremely rarely in the magnolialean block. The last evidence refers to biosynthetic pathways. Simple pathways, involving the acetate, mevalonate, amino acid or shikimate routes, operate separately in the biosynthesis of individual micromolecules in all possible ancestors and in both angiospermous blocks. Apart from polyketides (condensation of acetates) and terpenoids (condensation of mevalonate derived units), this primitive condition is exemplified by lignans (two cinnamyl alcohols), neolignans (two propenyl- or allylphenols), biflavonoids (two flavones), methylenebiphloroglucinols (two methylated phloroglucinols), terphenyl derivatives, benzylisoquinoline alkaloids, betacyanins (two phenylalanines or tyrosines in all three) and *Calycanthus* alkaloids (two tryptophanes). Mixed pathways, involving combinations of these routes (for instance the shikimate plus the mevalonate route, the mevalonate plus the amino acid route), which are rare in the synthesis of individual compounds in pre-angiosperms and the magnolialean block, are common in the rosiflorean block. Betaxanthins (tyrosine plus ornithine), anthranilate derived alkaloids (anthranilate plus, alternatively, polyketides, acetate and mevalonate, phenylalanines or proline), esters of angelic, tiglic or other ramified acids with four to seven carbon atoms (amino acids plus alcohols based on terpenoids, pyrrolizidine alkaloids etc.), prenylated phenolics (mevalonate derived units plus coumarins, acetophenones, flavonoids, etc.), pyrrolizidine alkaloids (ornithine plus acetate) and indole alkaloids (tryptophane plus mevalonate) (McKey, 1980) exemplify these advanced situations.

In this perspective are the data consistent with the theory above according to which the shikimate pathway was envisaged to have reached its extreme primary metabolites prior to the origin of the flouering plants (Kubitzki and Gottlieb 1984a). With the amplification of the oxidation potential of the plant cell oxidative dimers of these allyl- and propenylphenols, the neolignans, were formed in Magnoliiflorae, generally considered to represent the most primitive angiosperms. The abbreviation of the final steps of the shikimate pathway would result in the accumulation of phenylalanine and tyrosine. The interaction of such metabolites, again through reactions involving oxidation, leads to benzylisoquinolines, presumably the first alkaloidal types of angiosperms to condition their coevolution with mammals (Ehrlich ana Raven, 1965). The biosynthetic complexity of these alkaloids increases from the simplest aporphines of Magnoliiflorae in three directions to the berberines, morphines and thebaines of Ranunculiflorae, to the phenylethylisoquinolines and the benzyl phenylethyl amines of Liliiflorae, and to the betalains of Caryophylliflorae (which also produce mescalines and β-carbolines) Gomes and Gottlieb 1980). Further shortening of the shikimate pathway with respect to the synthesis of secondary metabolites leads to the accumulation of 5-dehydroshikimic acid, the precursor of gallic and ellagic acid derived tannins, and of chorismic acid, the precursor of anthranilate and of tryptophane derived alkaloids.

With gallic acid the possibilities of diversifying the production of allelochemicals through gradual curtailment of the shikimate pathway seem exhausted and a switch-over to the exploration of the acetate pathway does occur. A complete supression of the shikimate pathway does not occur since the aromatic amino acids continue to be produced. Besides, cinnamate surplus, from reduced consumption for the production of lignins, may account for a certain abundance of lignans, coumarins and even flavonoids, although the latter are subjected to selective forces different from those governing the presence of other secondary metabolites in herbaceous forms. One instructive case in point is provided by the Araliales which contain the closely allied families Araliaceae and Apiaceae. While the latter are mainly herbaceous and make ample use of cinnamate in the synthesis of coumarins, no such substances have been detected so far in the predominantly woody counterpart, the Araliaceae. Nevertheless, in these and especially in even more highly advanced angiosperm groups shikimate derived secondary metabolites play a relatively minor role. In these lineages the full potential of mevalonate utilization has led to steroid alkaloids, iridoids, iridoid alkaloids and sesquiterpene lactones and that of acetate utilization has led to polyacetylenes.

Steroidal alkaloids and sapogenins are found in advanced monocotyledonous taxa of the magnolialean block as well as in the Solaniflorae, sesquiterpene lactones and polyacetylenes characterize the Asteriflorae and iridoids are very widespread in the Gentianiflorae-Lamiiflorae. Among these three most hibhly advanced rosiflorean groups (Dahlgren, 1983) the Solaniflorae stand chemically somewhat closer to the Asteriflorae, both having comparable flavonoid chemistries (Gottlieb, 1982) and possessing tiglates (Kitagawa and Gottlieb, 1984), than to the Gentianiflorae-Lamiiflorae complex. While chemical connections of the Solaniflorae to the bulk of the rosiflorean block remain unsettled, connections possibly through Rutiflorae, to Araliiflorae with culmination in Asteriflorae are suggested by chemical continuities concerning sesquiterpene lactones (Emerenciano et al 1985) and polyacetylenes (Ferreira and Gottlieb, 1982), and connections, possibly through Rosiflorae, to Corniflorae with culmination in either Gentianiflorae or Lamiiflorae are suggested by chemical continuities concerning iridoids (Kaplan and Gottlieb, 1982).

In conclusion, gradual curtailment of the shikimate pathway for the production of primary precursors to biosynthetic groups of micromolecules constitutes a general trend in angiosperms. It is superimposed by a diversificatory trend within each micromolecular group, compatible with the enhanced biosynthetic power emanating from the increase in oxidation-reduction potential. These observations can be tentatively rationalized considering metabolic costs and effectiveness of deterrence against herbivores.

MICROMOLECULAR EVOLUTION AND PLANT CLASSIFICATION

Natural Products Chemists have endeavoured during the past few decades to contribute to the classification of plants. The potentialities of the approach were revealed by Erdtman (1973) for gymnosperms and by Hegnauer (1962-1973) for angiosperms, to quote only the two major exponents of the field. Indeed, chiefly on the level of the family and below chemists have achieved some convincing successes (for a summary see Gershenzon and Mabry,1983) and morphologists reluctantly (Heywood,1973) started to apply this old-new tool even to the family level and above. Three of the latest systems of angiosperm classification (Takhtajan,1980; Cronquist,1981; Thorne,1981) pay some attention to chemical criteria for the placement of taxa, and the fourth one (Dahlgren, 1980) relies more heavily upon them, especially for the realignment of many sympetalous families into "iridoid" and "sesquiterpene lactone/polyacetylene" blocks.

However, the presence or absence of compounds as classificatory criterion may be misleading. The complete range of precursors of natural products was present in angiosperms from the start, and the fact that e.g. benzylisoquinoline alkaloids and pyrones appear in Lauraceae, Rutaceae and Asteraceae, that phenylethylisoquinoline alkaloids appear in Cephalotaxaceae, Liliaceae and Aquifoliaceae, or that esters of angelic and tiglic acids appear in Schizandraceae, Euphorbiaceae and Solanaceae is not necessarily an indication of close relationship. Such direct application of micromolecular data is useful only on lower hierarchic level within taxa which are also morphologically homogeneous. Even in this favourable circumstance only versatility of structural variation confers a biosynthetic group of micromolecules status of a valid chemosystematic marker (Gottlieb 1982).

All this means of course that emphasis on the structure of accumulated metabolites must be shifted to something else. Birch (1963) suggested considering alterations of biosynthetic pathways. However, it is usually impractical to inquire into the biochemical history of a constituent before daring to think about its significance, physiologically, systematically, ecologically or otherwise (Bate-Smith,1983; personal communication). Even more seriously, no procedures existed to assess the meaning of such alterations with plant evolution (Birch,1973). And finally we should not loose sight of phenetic definability (morphologic, micromolecular etc.) as one of the goals in the organization of affinity-groups into formal taxa (Cronquist 1983). Phylogenetic classifications based on concealed evidence (amino acid sequence data for macromolecules, biosynthetic pathways for micromolecules) may deviate to a considerable extent from a phenetically useful classification (Dahlgren 1983), such as, in the case of a micromolecularly based one, in the selection of taxa with predictively useful or novel chemicals or in ecological studies.

Bate-Smith (1973) gave the first step in the right direction drawing attention to the dynamic distribution of gallo- and ellagitannins as well as of flavonols. The next step consists in the quantitative measurement of the evolutionary trends referred to above in order to demonstrate micromolecular continuities and disjunctions (Gottlieb,1982) and this is precisely the major challenge facing the chemically inclined systematist at present time.

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