**Molecular Phylogenetics of Phyllanthaceae: Evidence from Plastid matK and Nuclear PHYC Sequences**

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Plastid matK and a fragment of the low-copy nuclear gene PHYC were sequenced for 30 genera of Phyllanthaceae to evaluate tribal and generic delimitation. Resolution and bootstrap percentages obtained with matK are higher than that of PHYC, but both regions show nearly identical phylogenetic patterns. Phylogenetic relationships inferred from the independent and combined data are congruent and differ from previous, morphology-based classifications but are highly concordant with those of the plastid gene rbcL previously published. Phyllanthaceae are monophyletic and gives rise to two well-resolved clades (T and F) that could be recognized as subfamilies. DNA sequence data for Keayodendron and Zimmermannopsis are presented for the first time. Keayodendron is misplaced in tribe Phyllanthae and belongs to the Bridelia alliance. Zimmermannopsis is sister to Zimmermannia. Phyllanthus and Cleistanthus are paraphyletic. Savia and Phyllanthus subgenus Kriganelia are not monophyletic.

**Key words:** Malpighiales; matK; molecular phylogenetics; Phyllanthaceae; PHYC; systemsatics.

Phyllanthaceae are a morphologically diverse pantropical family of about 2000 species in c. 60 genera. They have been segregated along with Pandaceae, Picrodendraceae, and Puertojivaceae from Euphorbiaceae sensu lato (s.l.), following recent molecular work (Savolainen et al., 2000; APG II, 2003). The molecular systematics of Phyllanthaceae have been investigated as part of a larger multigene study on the systematics of Euphorbiaceae s.l. The largest sampling used plastid rbcL sequences, and over 350 Euphorbiaceae s.l. sequences including 76 (74 taxa) of Phyllanthaceae, to assess subfamilial and tribal relationships (i.e., Wurdack and Chase, 1999; Wurdack, 2002; Wurdack et al., in press). Two clades of Phyllanthaceae found in these molecular analyses (Wurdack et al., in press, and here) are nearly identical to the suprageneric classification of Webster (1994) and Radcliffe-Smith (2001), but the remaining clades do not correspond to previous tribal classifications. For a more detailed history of Phyllanthaceae classification, see Wurdack et al. (in press).

The matK gene is one of the most rapidly evolving plastid protein-coding regions (Wolfe, 1991). It is approximately 1550 base pairs (bp) long and encodes a maturase involved in splicing type II introns from RNA transcripts (Wolfe et al., 1992). Recent studies have shown the usefulness of this gene for resolving intergeneric or interspecific relationships among flowering plants, e.g., Malpighiaceae (Cameron et al., 2001), Poaceae (Li and Hilu, 1996), Cornaceae (Xiang et al., 1998), Nicotiana (Aoki and Ito, 2000; Clarkson et al., in press), Chrysosplenium (Soltis et al., 2001), Hypochaeris (Samuel et al., 2003), Orchidaceae (Goldman et al., 2001; Salazar et al., 2003) and most recently across all angiosperms (Hilu et al., 2003).

Low-copy nuclear protein-coding genes remain underutilized in phylogenetic studies, despite the need for nuclear comparisons with trees produced from plastid regions (Doyle, 1992, 1997). The nuclear regions most commonly used in phylogenetic studies are from high-copy ribosomal loci, such as ITS (Baldwin et al., 1995). The multigene phytochrome (PHY) family is a potential source of phylogenetic information. Phytochromes are photoreceptors for red and far-red light in all land plants (Quail, 1991) and mediate diverse developmental responses throughout the life cycle of a plant. In angiosperms, five related sequences coding for phytochrome proteins designated PHY A-PHY E have been characterized in Arabidopsis thaliana (Sharrock and Quail, 1989; Clack et al., 1994). A simple way to sample putatively orthologous loci in the phytochrome gene family is to use locus-specific amplification primers. Phytochrome sequence data have provided a high degree of resolution within basal angiosperms (Mathews and Donoghue, 1999), Fabaceae (Mathews et al., 1995), Poaceae-Andropogoneae (Mathews et al., 2002), Malpighiaceae (Davis et al., 2002), and Malpighiales (Davis and Chase, 2004) and may be useful for resolving relationships within Phyllanthaceae. The overall rate of evolution of the PHY lineage is about 10 times faster than rbcL (Mathews et al., 1995).
This study analyzes the nuclear gene PHYC and the plastid gene matK to infer phylogenetic relationships within Phyllanthaceae and determine congruence of these two regions. We aim furthermore to evaluate the phylogenetic patterns obtained with rbcL sequence data (Wurdack et al., in press) with additional genetic markers as the basis for creating a revised tribal classification of Phyllanthaceae.

**MATERIALS AND METHODS**

**Plant material**—Forty-seven species (49 different accessions) from 30 genera (of the 60 genera recognized by Radcliffe-Smith [2001]) for Euphorbiaceae-Phyllanthoideae, representing five of 10 tribes, and six of 11 subtribes of Antidessaceae and Phyllanthaceae were included in the analyses (see Supplemental Data accompanying the online version of this article). The taxon set used in the matK analysis included 41 ingroup species (43 accessions) and excluded *Kueyenodendron*, whereas the analysis of PHYC included 44 ingroup species (45 accessions) and excluded *Uapaca*. Outgroup taxa for these analyses included representatives from several other families of Malpighiales (APG II, 2003) including: Clusiaceae, Euphorbiaceae sensu stricto (s.s.), Humiriaceae, Ochnaceae, Picrodendraceae, and Putranjivaceae (see Appendix 1 in supplemental data accompanying the online version of this article). Forty-one species (42 accessions) representing all 50 sampled genera were analyzed in combination. Because of our focus on Phyllanthaceae, and due to the limited sampling of other Malpighialine lineages, no close relationship among outgroup families should be inferred from our results. Most samples were obtained from the DNA Bank of the Royal Botanic Gardens, Kew, UK (http://www.rbgkew.org.uk/data/dnabank/homepage.html). In addition, silica gel dried specimens collected in Madagascar and Sri Lanka were included.

**DNA extraction and amplification**—Total DNA was extracted from material stored in silica gel following the 2 × CTAB (cetyltrimethyl ammonium bromide) procedure of Doyle and Doyle (1987). Most of the DNA samples obtained from herbarium specimens were purified by cesium chloride/ethidium bromide gradient (1.55 g/mL). Polymerase chain reaction (PCR) amplification was carried out using PCR ready mix (AB-0619/LD from Abgene, Vienna, Austria) and 2–8 ng (1 µL of 2–8 ng/µL) of template total DNA for a 50 µL reaction mixture. The PCR profile consisted of an initial 2 min pre-denaturation at 94°C and 35 cycles of 1-min denaturation at 94°C, 30-s annealing at 48°C, and 1-min extension at 72°C followed by a final extension of 10-min at 72°C. Amplified fragments were checked with 1% agarose gel, and the double-stranded DNA fragments were purified using QIAquick gel purification kit (Qiagen, Margaritella, Vienna, Austria).

We designed new amplification primers for matK spanning the entire region plus part of the matK intron 5′ (matK 570F) and matK3′ (1710R) (Table 1). Figure 1 shows the positions of the matK intron in which matK is embedded and the positions of the primers used in this study. Degraded DNA from herbarium specimens was amplified in 5 or 6 fragments that were sequenced separately and then combined into a single contig.

For the PHYC gene, we designed our own primers from the available sequences in GenBank. Initially PCR products were cloned by ligation into pGEM-T vector systems (Promega GmbH, Mannheim, Germany); XL1-Blue competent cells were transformed according to the manufacturer’s protocol (Strategene Europe, Amsterdam, The Netherlands). Resulting colonies were screened for plasmids with inserts, and five positive clones were amplified and then sequenced using the same primers. To avoid time-consuming cloning, another set of primers from the aligned cloned sequences of some species was designed PHYC-F [5′-CCAGCTACTGATAATCCGTAGCTTC-3′] and PHYC-R [5′-CCAGCTTCCATAGCTTGATCTAGCT-3′], which enabled us to directly sequence a fragment of approximately 600 bp. This fragment is in the first exon of the PHYC gene starting from 800 bp downstream. The entire gene is 3571 bp long in *Arabidopsis thaliana* and has two introns, 136 and 98 bp in length. Primer positions of the sequences used in this study are shown in Fig. 2.

**Sequencing**—The purified fragments were directly sequenced on an ABI 377 automated sequencer (Applied Biosystems, ABI, Vienna, Austria) using dye terminator chemistry following the manufacturer’s protocol. Cycle sequencing reactions were performed for each template using each of the two primers used for PCR amplification and internal primers for matK if required. Both strands were sequenced. The programs Sequence Navigator and AutoAssembler (ABI) were used to edit and assemble the complementary sequences. These sequences have been deposited in GenBank (Appendix 1 in Supplemental Data that accompanies the online version of this article).

**Sequence alignment and phylogenetic analyses**—Alignments were obtained using the program Clustal V (Higgins et al., 1992) and improved by visual refinement. In the matK sequences, large gaps (in multiples of three) were often needed. Individual and combined parsimony analyses of matK and PHYC were performed using the program Mr. Bayes 3.1 (Huelsenbeck and Ronquist, 2001). For the matK gene, the 5′-flanking and 3′-untranslated regions were included.

**Table 1. Primer sequences used in this study for the amplification and sequencing of the trnK intron and matK gene.**

<table>
<thead>
<tr>
<th>Primer</th>
<th>Sequence</th>
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<tr>
<td><em>trnK</em> 570F</td>
<td>5′-TCC AAA ATC AAA AGA GCG ATT GG-3′</td>
</tr>
<tr>
<td>80F</td>
<td>5′-CTA TAC GCA TCT ATC TTT CGG GAG T-3′</td>
</tr>
<tr>
<td>390F</td>
<td>5′-CGA TCT ATT CAT TCA ATA TTT C-3′</td>
</tr>
<tr>
<td>800F</td>
<td>5′-CAT GCA TTA TGT TAG ATA TCA AGG-3′</td>
</tr>
<tr>
<td>1200F</td>
<td>5′-GA (CT) TCT GAT ATT ATC AAC CGA TTT G-3′</td>
</tr>
<tr>
<td>190R</td>
<td>5′-ATT CGA GTA ATT AAA CGT TTT ACA A-3′</td>
</tr>
<tr>
<td>950R</td>
<td>5′-GTT CCA ATT CCA ATA CTC GTG AAG-3′</td>
</tr>
<tr>
<td>1300R</td>
<td>5′-AAA AT (AG) ACA TGG ACA TAA ATT GAC AA (AG) G-3′</td>
</tr>
<tr>
<td>1710R</td>
<td>5′-GCT TGC ATT TTT CAT TGC ACA CG-3′</td>
</tr>
<tr>
<td><em>matK</em></td>
<td></td>
</tr>
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<td>8</td>
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**Fig. 1.** Location of the *matK* gene in the *trnK* intron. Arrowheads indicate the location and direction of the primers. The *trnK* 3914F primer is from Johnson and Soltis (1994); all others are new to this study.

**Fig. 2.** PHYC (55716–59286) in the fifth chromosome of *Arabidopsis thaliana* (Genbank accession number AB005236). Arrowheads (PHYC F and PHYC R) indicate positions of our primers.
for sequence evolution (Rodrõ Águez et al., 1990). Four Markov chains starting on sonema, supported as sisters with BP 100). In the second, cf. (subgenus Phyllan-
to two clades each with BP 100. The ®rst contains (BP 100) clade containing all genera with phyllanthoid branch-
of clade F1. Ly supported (BP 60) clade containing the remaining members
(DELTRAN, delayed transformation, optimization) above each
searches generated three equally parsimonious trees with 1845
602 (37%) were potentially parsimony informative. Heuristic
searches were conducted with equal weights, 1000 replicates of ran-
1985) with the method implemented in MrBayes. The general
produced for the combined sequence data using Bayesian inference (Larget
both genes had similar models an independent, model-based estimate was
visualized to determine congruence of the two data sets (Whitten et al., 2000).
Model evaluation was done for both matrices independently using Mr
Bayes 2.01 (Huelsenbeck and Ronquist, 2001) to find the best fit. Because
two genera had similar models an independent, model-based estimate was
produced for the combined sequence data using Bayesian inference (Larget
and Simon, 1999) with the method implemented in MrBayes. The general
time reversible model (GTR + I + G, nst = 6, rate = invgamma) was chosen for
sequence evolution (Rodriguez et al., 1990). Four Markov chains starting
with a random tree were run simultaneously for one million generations, sam-
pling trees at every 100th generation. Trees prior to stationarity (3000 trees)
were excluded and the remaining trees used to construct in PAUP* a consen-
sus tree with percentages (Bayesian posterior probabilities [PP]) of trees com-
patible with the single tree. We will not report posterior probabilities here
because these have been demonstrated to be overestimates of confidence (Su-
zuki et al., 2002).

RESULTS

Analysis of the matK gene—The aligned matK matrix con-
sisted of 1612 bp, of which 840 positions were variable, and
602 (37%) were potentially parsimony informative. Heuristic
searches generated three equally parsimonious trees with 1845
steps. One of the equally parsimonious trees with Fitch lengths
(DÈLTRAN, delayed transformation, optimization) above each
branch and bootstrap percentages (BP $> 50$) below each branch is
shown in Fig. 3.

Phyllanthaceae are weakly supported (BP 60) as monopha-
yletic and are split into two strongly supported (both BP 100)
clades T and F (tanniferous and fasciculate clade, respec-
tively). The first major clade (T) corresponds to tribes Anti-
desmeae + Bischofieae sensu Radicliffe-Smith (2001) and
contains four subclades. One strongly supported (BP 100) subcla-
de within clade T includes Aporosa and Baccarea (Antides-
meae-Scepinae); a second (BP 100) includes Apodiscus
(Antidesmeae-Scepinae) as sister to the members of Antides-
meae-Antidesminae included in this analysis, Antidesma +
Theacaroris (BP 100); the third and fourth Uapaca (monoge-
eric Antidesmeae-Uapacinae) and Bischofia (monotypic Bis-
chofieae), respectively, are weakly placed relative to one an-
other and to the other two subclades within clade T. Each of
the two representative species of Baccarea and Theacaroris
are moderately well supported (BP 82 and 87, respectively) as
sister taxa.

The second major clade (F) is split into four well-supported
(BP 100) subclades (F1, F2, F3, F4). The first (F1) comprises
all members of Phyllanthaceae-Flueggeinae sensu Webster
(1994) included in this analysis, Flueggea is sister to the weak-
ly supported (BP 60) clade containing the remaining members
of clade F1. Margaritaria is then sister to a strongly supported
(BP 100) clade containing all genera with phyllanthoid branch-
ing (Webster, 1956). Phyllanthus is not monophyletic and falls
into two clades each with BP 100. The first contains Phyllan-
thus calycinus (subgenus Isocladas) and P. cf. fuscoluridus +
P. cf. mantssakariva (both subgenus Kirganelia section Ani-
sonema, supported as sisters with BP 100). In the second,
Fig. 3. One of the three most parsimonious trees obtained from the maximum parsimony analysis of the matK gene (length = 1845, CI = 0.63, RI = 0.82). Branch lengths (DELTRAN optimization) and bootstrap percentages (>50) are indicated above and below the branches, respectively. Arrowheads indicate nodes not present in the strict consensus tree. Hyphens (-) indicate BP < 50.
Fig. 4. One of the most parsimonious trees obtained from the maximum parsimony analysis of the PHYC (length = 1861 steps, CI = 0.45, RI = 0.65). Branch lengths (DELTRAN optimization) and bootstrap percentages (>50) are indicated above and below the branches, respectively. Arrowheads indicate nodes not present in the strict consensus tree. Hyphens (-) indicate BP < 50.
least two clades. The first (BP 88) includes \textit{P. calycinus} (subgenus \textit{Isocladus}), plus a well-supported (BP 99) clade consisting of three taxa of subgenus \textit{Kirganelia} section \textit{Anisomena}. The second clade (BP 96) is a polytomy comprised of several species of \textit{Phyllanthus} (\textit{P. lokohensis} (subgenus \textit{Phyllanthus}), plus two accessions of \textit{P. nummularifolius} (\textit{Kirganelia-Pentandra} or \textit{Tenellantha}) and \textit{P. epiphyllanthus} (subgenus \textit{Xylophylla}), plus the well-supported (BP100) clade \textit{Glochidion} (\textit{Breynia + Saurous}). Within the last subclade, \textit{Saurous + Breynia} are weakly supported as sisters (BP 54), and support for the two species of \textit{Breynia} is moderate (BP 87).

\textit{Bridelia} and \textit{Cleistanthus} (both Bridelieae), \textit{Keayodendron} and \textit{Pseudolachnostylis} (both Phyllanthaceae-Pseudolachnostylidinae), \textit{Gonatogyne}, \textit{Savia} and \textit{Lachnostylis} (all Wielandieae) form a strongly supported (BP 100) clade \textit{F2}. As with \textit{matK}, \textit{Gonatogyne + Savia} on the one hand, and \textit{Bridelia}, \textit{Cleistanthus} and \textit{Pseudolachnostylis} on the other hand form well-supported (BP 80 and 83) clades. \textit{Cleistanthus} appears non-monophyletic as in \textit{matK}. \textit{Cleistanthus oblongifolius} clusters with \textit{Bridelia} again (BP 97), but \textit{C. perrieri} forms a well-supported (BP 97) clade with \textit{Pseudolachnostylis}. \textit{Keayodendron}, which was not sampled in the \textit{matK} analysis, is weakly supported as sister to all other members of clade \textit{F2}.

Clade \textit{F3} is weakly supported (BP 76) and consists of two sister clades: one containing \textit{Actephipha} and \textit{Leptopus}, and the other \textit{Poranthera} and \textit{Meineckia} (\textit{Zimmermannia + Zimmermanniopsis}). Each of these clades is supported with BP < 50. The two species of \textit{Leptopus} are united by BP 100. \textit{Meineckia} (\textit{Zimmermannia + Zimmermanniopsis}) is supported by BP 100, and the sister-group relationship of \textit{Zimmermannia} and \textit{Zimmermanniopsis} has weak support (BP 56). The position of \textit{Heywoodia} is weakly supported as sister to \textit{F3}, a placement identical to that inferred from \textit{matK}.

The western Indian Ocean Wielandieae again group in the highly supported (BP 100) clade \textit{F4}. No further bootstrap supported resolution is obtained with \textit{PHYC} in this clade.

\textbf{ Parsimony and Bayesian analysis of combined data—}

Since the consensus trees obtained with the individual gene matrices were topologically congruent, the two data sets were combined for further analysis. The aligned combined \textit{matK} and \textit{PHYC} matrix consisted of 2277bp. The heuristic search on this data set resulted in six equally most parsimonious trees with 3440 steps (Fig. 5). Bayesian analyses of the combined matrix produced a tree (not shown) that is nearly identical to the parsimony tree. All clades with high posterior probabilities (PP 1.0) are also present and receive at least moderate bootstrap support in the parsimony analysis.

The most notable result of this combined parsimony analysis is the high support (BP 100) for \textit{Phyllanthaceae}. The two major clades (T and F) are well-supported (both with BP 100). The topology of clade T is identical with that in the \textit{matK} tree, with similarly high bootstrap percentages. Clades F1–F4 are all well supported (BP 100) and resolved into F1, F2, and (F4 (\textit{Heywoodia + F3})).

Clade F1 is strongly supported (BP 100). The positions of \textit{Flueggea} and \textit{Margaritaria} equal those in the \textit{PHYC} analysis. The topology of all other nodes agrees with both single-gene analyses, but bootstrap percentages vary slightly.

Clade F2 is well-supported in the combined analysis (BP 100). The topology of the strict consensus tree is identical to that of the \textit{PHYC} analysis, having low support for internal nodes. Clade F3 shows an identical topology and similarly high bootstrap percentages in the combined and \textit{matK} analyses. Placement of \textit{Heywoodia} as sister of the F3 clade is moderately supported (BP 86), compared to the weak support in the single-region analyses. Clade F4 is supported by BP 100 in all three analyses, but support for internal nodes does not increase in the combined analysis as in clade F2.

\textbf{DISCUSSION}

\textit{matK} and \textit{PHYC}—The utility of \textit{matK} for resolving generic or species level relationships is similar or greater than that of nuclear rDNA ITS (Solntsev \textit{et al.}, 1996). Indels are likely to be present in a \textit{matK} data matrix of any taxonomic breadth. In our analysis \textit{matK} resolves clades well at the tribal and generic levels and provides high bootstrap percentages for the different clades (Fig. 3). Although there was a greater percentage of potentially informative sites in \textit{PHYC} (65\%) than in \textit{matK} (37\%), the latter gene provided higher bootstrap percentages for the major clades and appears to be of greater phylogenetic utility.

\textbf{Comparison with \textit{rbcl}—}For ease of reference, the clades recovered in this study are named in concordance with the \textit{rbcl} analysis of Wurdack \textit{et al.} (in press). Sampling for the \textit{rbcl} study (Wurdack \textit{et al.}, in press) was more comprehensive than in this study. All genera included here were also included in the \textit{rbcl} study, with the exception of \textit{Keayodendron} (clade \textit{F2}) and \textit{Zimmermanniopsis} (clade \textit{F3}). This study is also the first to include representatives of \textit{Phyllanthus} subgenus \textit{Kirganelia} section \textit{Anisomena} (clade \textit{F1}). The topologies of the combined \textit{matK/PHYC} (presented here) and \textit{rbcl} trees are consistent with one another. Major clades of \textit{Phyllanthaceae} (T, \textit{F1–F4}) recovered with \textit{rbcl} were also found with \textit{matK} and \textit{PHYC}. A single inconsistency in the topologies of the three genes is the placement of \textit{Cleistanthus perrieri} (clade \textit{F2}). The position of this species in the \textit{rbcl} tree is identical to that in the \textit{matK} tree (sister to \textit{Pseudolachnostylis} (\textit{Bridelia + Cleistanthus oblongifolius})) but differs from the \textit{PHYC} tree and the combined \textit{matK/PHYC} tree (sister to \textit{Pseudolachnostylis} only). It is possible that there is conflicting signal for the position of \textit{Pseudolachnostylis}. Paraphyly of \textit{Cleistanthus} was already reported and discussed in Wurdack \textit{et al.} (in press).

The combined \textit{matK/PHYC} tree shows higher support for individual clades and better resolution than that obtained from \textit{rbcl}. It should be noted that outgroup sampling in these studies is not identical and may affect support for the \textit{Phyllanthaceae} node. Most prominently, monophyly of \textit{Phyllanthaceae} is supported with BP 100 (rather than just BP 73 with \textit{rbcl}). The two major clades (T and F) have slightly improved support (BP 100 for both vs. BP 98 and 91 in \textit{rbcl}). Support for the subclades \textit{F1–F4} has increased from BP 95–100 to BP 100 for all four clades in the combined analysis.

Monophyly of \textit{Thecacoris} is confirmed in the \textit{matK} and combined analysis with moderate support (BP 87 and 86, respectively). The sampled species represent the two major groups, \textit{Thecacoris} s.s. and \textit{Cyathogyne}, recognized at generic rank by some authors (e.g., Pax and Hoffmann, 1922; Léonard, 1995). Their relationship received BP < 50 in the \textit{rbcl} analysis.

Two more instances of improved resolution are noted here with the caveat that sampling in the \textit{rbcl} analysis was more comprehensive in these clades: \textit{Antidesma + Thecacoris} are
Fig. 5. One of the six most parsimonious trees of the combined analysis of matK and PHYC (length = 3440, CI = 0.59, RI = 0.75). Branch lengths (DELTRAN optimization) and bootstrap percentages (>50) are indicated above and below the branches, respectively. Arrowheads indicate nodes not present in the strict consensus tree. Hyphens (-) indicate BP < 50.
strongly supported sister taxa with *Apodiscus* sister to both, whereas with *rbcL* no further resolution was obtained for these three taxa. *Antidesma* and *Thecacoris* closely resemble each other, and the genera lack distinguishing generic characters in staminate specimens (both are dioecious). In pistillate specimens, the unilocular drupes of *Antidesma* are clearly different from the trilocular schizocarps of *Thecacoris*. In the *matK* and combined analyses, *Leptopus* and *Actephipha* are grouped together (BP 98), which is biogeographically plausible (both are distributed in Asia and Australia) even though it contradicts wood anatomical (Mennega, 1987) and embryological (Webster, 1994) arguments used to distance *Actephipha* (previously in Wielandieae) from *Leptopus* (Phyllanthoideae-Leptopinieae).

**Drypetes madagascariensis**—The high genetic divergence of the two accessions of *Drypetes madagascariensis* (Putranjivaceae, outgroup for this study) may indicate heterogeneity of the species in its present circumscription. Most species of the dioecious genus *Drypetes* have few distinguishing morphological characters, and *D. madagascariensis* is noted for its remarkable variability (McPherson, 2000). The accession here marked as *D. cf. madagascariensis* differs from the majority of specimens solely by the lack or poor development of the fifth sepal but agrees in all other macro-morphological characters (the accession is in fruit) with *D. madagascariensis*.

**Position of Zimmermanniopsis**—*Zimmermanniopsis uzungwaensis* has been variously accepted at generic rank (Radcliffe-Smith and Harley, 1990; Webster, 1994; Radcliffe-Smith, 2001) or included in *Meineckia* as section *Zimmermanniopsis* (Radcliffe-Smith, 1997; Govaerts et al., 2000). Placement in all analyses presented here confirms the close relationship of *Zimmermanniopsis* to *Zimmermannia*, and to *Meineckia* but more sampling is needed to determine the status of these taxa. A more comprehensive study of subclade F3 is presently underway at the Royal Botanic Gardens, Kew. One objective of this study is to clarify the taxonomy of the *Meineckia/Zimmermannia/Zimmermanniopsis*-complex.

**Placement of Keayodendron**—The monotypic genus *Keayodendron* has not previously been included in molecular phylogenetic analyses. Initially described as a species of *Casearia* (formerly Flacourtiaeae; Salicaceae-Samydeae in Chase et al., 2002), Leandri (1959) transferred it correctly to Euphorbiaeae-Phyllanthoideae and described the new genus *Keayodendron*. He positioned it near *Drypetes* (now Putranjivaceae) because of the general resemblance of leaves and inflorescences, but also pointed out similarities to *Bridelia* in floral and embryo morphology, most strikingly the extrastaminale staminate disc in *Bridelia* and *Keayodendron* (vs. a central staminate disc in *Drypetes*). He furthermore compared his new genus to *Pseudolachnostylis* and *Securinega*. The resemblance between *Keayodendron* and *Bridelia* had already been noted in the basionym *Casearia bridelioides* Gilg ex Engl. However, emphasis placed on the valvate sepalas in tribe Bridelieae previously obscured the close relationship of those taxa. Webster (1994: 41–42) placed *Keayodendron* in Phyllanthoideae-Pseudolachnostyliidae “for lack of a better alternative,” stating that “…it is quite possible that *Pseudolachnostylis* and *Keayodendron* may not be closely related to the rest of the genera.” He compared its fruits and aspect to *Bridelia*, but the lack of petals and the imbricate sepalas in *Keayodendron* deterred him from formally associating it with Bridelieae. Radcliffe-Smith (2001) followed Webster’s lead.

The molecular data place both *Keayodendron* and *Pseudolachnostylis* with *Bridelia* and *Cleistanthus* (Wurdack et al., in press, for *Pseudolachnostylis* only; this study). Stuppy (1996) came to the same conclusion and united these four genera in his *Bridelia* group according to their seed coat anatomy. *Bridelia*, *Cleistanthus*, and *Keayodendron* share a double disc in pistillate flowers (Radcliffe-Smith, 2001). This double disc is also described and illustrated in *Pseudolachnostylis* (Pax and Hoffmann, 1922, and P. Hoffmann’s own observations). It is a potential synapomorphy of this subclade because it is not present in *Gonatogyne* and *Sabia* (P. Hoffmann, unpublished data). The position of *Keayodendron* within clade F2 is at present unclear.

**Phyllanthus subgenus Kriganelia is not monophyletic**—*Phyllanthus* subgenus *Kriganelia* was proposed by Webster (1956) based on *Kriganelia* A. Juss. to accommodate species with phyllanthoid branching, five stamens, colporate pollen grains, and 3–10 carpels. He considered this variable subgenus to be primitive, comprising *P. sections Anisomena* and *Floribundii*. The latter section includes *P. nummulariifolius* and *P. tenellus* (Webster, 1957). Webster (1967) later described the new *P. section Pentandra* in subgenus *Kriganelia* to accommodate *P. nummulariifolius* and *P. tenellus* along with the type, *P. pentandra*. He stated (Webster, 1967: 334) that “…this section is significant phylogenetically because most of its taxa have precisely the habit and appearance of species of subg. *Phyllanthus*, from which they scarcely differ in anything more than the five-merous rather than three-merous androecium. Since *P. tenellus* is the only herbaceous diploid species with phyllanthoid branching, it and closely related taxa such as *P. capillipes* Schum. [= *P. nummulariifolius*] may be regarded as the nearest living equivalents of the taxa ancestral to subg. *Phyllanthus*.” Both of Webster’s studies focused on the Americas and dealt with few species of this predominantly Old World group.

Brunel (1975, 1987) studied the genus *Phyllanthus* extensively in continental Africa. He remarked on the heterogeneity of subgenus *Kriganelia* and proposed to segregate the species related to *Phyllanthus tenellus* Roxb. in a new subgenus *Tenellanthus* (Brunel, 1987) which was never validly published. Our study included for the first time species of both *P. subgenus Kriganelia* section *Anisomena*, as well as *P. subgenus Kriganelia* section *Pentandra* (*P. subgenus Tenellanthus* section *Tenellanthus*, nomen invalidum; Brunel, 1987). The three sampled taxa of section *Anisomena* belong to a morphologically homogeneous group with a center of diversity in Madagascar. All closely resemble *P. casticum*, and characters of the constituent taxa overlap. Species identification is provisional pending a taxonomic revision (M. Ralimanana and P. Hoffmann, unpublished data).

Placement of these taxa in our analyses corroborates Brunel’s (1975, 1987) view that subgenus *Kriganelia* is heterogeneous, as well as Webster’s (1967) comparison of his *P. section Pentandra* with subgenus *Phyllanthus*. *Phyllanthus nummulariifolius* is found in a subclade with *Breyxia*, *Gloechidion*, and *Saururus*, which in the *PHYC* analysis also contains *Phyllanthus epiphyllanthus* (subgenus *Xylophylly*) and *P. lokohensis* (subgenus *Phyllanthus*). Two accessions of *P. nummulariifolius* were sequenced to confirm this placement. The three accessions of subgenus *Kriganelia* section *Anisomena*
(P. cf. decipiens, P. cf. fuscoloridus and P. cf. mantsakariva) form a monophyletic group as predicted by their similar morphology. This clade is sister to *Phyllanthus calycinus* of subgenus *Isocladus* in this study with limited sampling in the largest genus of Phyllanthaceae (c. 800 species).

**Western Indian Ocean Wielandiae**—The centre of diversity for the taxa united here in clade F4 is Madagascar, with few species also represented in the Seychelles, the Comoro Islands, and the East coast of Kenya. They are morphologically similar despite being currently placed in the four different genera *Blotta*, *Petalodiscus*, *Savia* and *Wielandia*. The type of *Savia* is from Hispaniola and belongs in clade F2 as sister to *S. dictyocarpa* sampled here (Wurdack et al., in press). This shows the degree of taxonomic confusion surrounding this poorly known group. The lack of support for the internal nodes in this clade indicates that generic boundaries are in need of revision. The entire clade is revised in a forthcoming publication (Hoffmann and McPherson, in press).

**Conclusions**—Results of DNA sequence analyses using *matK* and *PHYC* correspond well with each other and with those separately obtained from analysis of *rbcL* (Wurdack et al., in press). Inclusion of missing genera and sampling of more taxa in problematic genera, namely *Cleistanthus* and *Phyllanthus*, as well as increasing the number of plastid markers analyzed and sequencing a longer fragment of low-copy nuclear *PHYC* may refine the phylogenetic hypothesis presented here.

*Note added in proof*: The high level of sequence divergence observed in the two accessions of *Drypetes madagascariensis* (outgroup taxa) may possibly be due the amplification of different *PHY* paralog, *PHYE* (in one of the accessions), instead of *PHYC*, which is otherwise used in our analyses.

**LITERATURE CITED**


Radcliffe-Smith, A., and M. M. Harley. 1990. Notes on African Eu-


