

Angiosperm Phylogeny Group Classification

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INTRODUCTION

Andrea Caesalpino (1583), proposed the first methodical arrangement of plants into 15 'higher genera' on the basis of the structure of trunk and fructification. In the mid 18th century, Linnaeus published 'Species Plantarum' with a complete list of 7000 species of flowering plants known at that time which were classified under 1000 genera and 23 classes. Contributions of Linnaeus and his immediate successors have formed a strong base for the current day classification. Linnaeus and other botanists till the end of 20th century (e.g. Bentham & Hooker, 1862-83) classified flowering plants for ease of the identification. Systematic research in the past 150 years and particularly during the last four decades have greatly influenced our views on the classification of plants especially angiosperms. Cladistic information strongly points to the fact that simplistic division of angiosperms into monocots and dicots do not reflect phylogenetic history. During 1990s, reconstruction of flowering plant phylogeny took a great step forward. Rapidly accumulating DNA sequences, particularly from the plastid gene *rbcL* provided new and informative sets of data. Cladistic analysis of these was also much improved through the development of phylogenetic theory and application to analyse the large data sets.

To establish a consensus view of the classification of flowering plants, an international group of flowering plant systematists christened as the Angiosperm Phylogeny Group (APG), came together to propose a classification based on sound phylogenetic data sets in 1998. Till 2010, three versions of classifications have been proposed by this group that was published in 1998, 2003 and 2009, each superseding the previous systems. Peter F.

Stevens, one of the authors of all three of the APG classifications maintains a web site, APweb, hosted by the Missouri Botanical Garden, which regularly update the information regularly since 2001 (Stevens, 2001 onwards). This web site is a prime source of information for the latest research in angiosperm phylogeny.

APG CLASSIFICATION (APG, 1998)

With the efforts of 29 botanical systematists around the world, a new system of classification has been proposed under the umbrella of Angiosperm Phylogeny Group succinctly known as APG 1998. This system is based on sound phylogenetic principle of arranging taxa on the basis of established monophyly. It relied on the synthesis of information from the disciplines of morphology, anatomy, embryology, phytochemistry and more strongly on molecular studies with reference to DNA sequences of two chloroplast genes (cpDNA; *atpB* and *rbcL*) and one gene coding for ribosomes (nuclear ribosomal 18s DNA).

APG 1998 recognized 462 families, which were grouped into 40 monophyletic orders classified under few informal monophyletic higher groups: monocots, commelinoids, eudicots, core eudicots, rosids including eurosids I and eurosids II, asterids including eausterids I and euasterids II. The focus was on orders and less on families. Many families were not classified to order because their positions were either uncertain or unknown. In this classification, there are 81 unplaced families, 11 placed towards the beginning, 25 towards the end and 45 in the informal groups. Alternative options are provided for some groups, in which a number of families can either be regarded as separate taxa or can be merged into a single larger family.

APG 1998 addressed the deficiencies of earlier classifications with respect to phylogenetic tree of flowering plants and establishment of major groups or clades within. The

authors chose to adopt a broad approach in defining the limits of orders, resulting in the recognition of 40 orders, compared to, for example, 232 in Takhtajan's classification (Takhtajan 1997). In APG 1998 classification, the monocots are recognized as a monophyletic clade, but the dicots are placed in separate groups, some are basal to monocots and the remaining is considered as eudicots or 'true dicots'. Various monocot taxa are placed in between primitive angiosperms and eudicots, thus overcoming the problem of paraphyly.

APG II (2003)

After five years since the publication of APG classification, considering further advances in flowering plant phylogenetic research, an updated version of the APG classification (APG II) was proposed in 2003. The APG II classification recognized 457 families (5 less than APG 1998) and 45 orders (5 more than APG 1998). Within 457 families, there are 55 optional segregates (presented in square brackets), thereby considering minimum number of families as 402. Of the 45 orders, 44 are placed in 11 informal groups which were considered more or less monophyletic. Contrary to APG 1998 which has 81 unplaced families, in APG II, this number has been reduced to 40. The list of unplaced families in the beginning has been reduced to 4 and uncertain families towards the end to 9.

APG III (2009)

To fill further gaps in APG II and to develop a much more stabilized classification, with recommendations of different scientist groups around the world, a revised and updated version of APG was published in October, 2009 by a team of 8 scientists in the name of APG III. This classification followed Backlund & Bremer (1998) principles of rank-based phylogenetic classification that is applicable at all levels.

APG III recognizes 413 families. Except ten families, *viz.*, Dasygogonaceae, Ceratophyllaceae, Sabiaceae, Dilleniaceae, Boraginaceae, Vahliaceae, Icacinaceae,

Metteniusaceae, Oncothecaceae, Cynomoriaceae and Apodanthaceae, rest of the 403 families are assigned to 59 orders. Of these 59 orders, Amborellales, Nymphaeales, Austrobaileyales and Chloranthales (covering 8 families) are unplaced, i.e. not included under any clade, and kept in the beginning. The remaining 55 orders are assigned to 11 clades or groups: magnoliids, monocots, commelinids, eudicots, core eudicots, rosids, fabids, malvids, asterids, lamiids and campanulids. Order Ceratophyllales is considered as probable sister of eudicots. Cynomoriaceae, Apodanthaceae and the genera *Gumillea* Ruiz & Pav., *Petenaea* Lundell and *Nicobariodendron* Vasudeva and Chakrab. were considered as taxa of uncertain position. An abstract of APG III classification with respect to groups, orders and families is presented in **Table 1** and the complete list of 413 families as per LAPG III sequence and along with number of genera and species for each family, world distribution and representative genera (including type genus) can be consulted through Rao and Prasanna (2010).

New orders *viz.*, Amborellales, Berberidopsidales, Bruniales, Buxales, Chloranthales, Escalloniales, Huerteales, Nymphaeales, Paracryphiales, Petrosaviales, Picramniales, Trochodendrales, Vitales and Zygophyllales are recognized in APG III. Many genera and families which were unplaced in APG and APG II classifications are now included in respective orders; this includes Hydatellaceae (Nymphaeales), Huaceae (Oxalidales), Rafflesiaceae (Malpighiales), Aphloiaceae, Geissolomataceae and Strasburgeriaceae (all Crossosomatales), Picramniaceae (Picramniales), Cytinaceae (Malvales), Balanophoraceae (Santalales), and Mitrastemonaceae (Ericales).

Newly segregated families of APG III for genera previously treated under other APG-recognized families includes Calophyllaceae (Malpighiales), Capparaceae and Cleomaceae (both Brassicales), Linderniaceae and Thomandersiaceae (both Lamiales). Many families that were in square brackets in APG II are now treated clearly: Brassicaceae *s.l.* have been split

into 3 families viz., Brassicaceae *s.s.*, Capparaceae and Cleomaceae. However, in some cases, the broader circumscriptions are retained, e.g., Amaryllidaceae, Asparagaceae and Passifloraceae. The positions of Ceratophyllaceae, Chloranthaceae and Picramniaceae have been clarified, for which additional orders have been proposed that were not previously recognized.

Of the 413 families of APG III, 121 are monotypic, represented by a single genus and 28 of them are represented by single species. As per the current update information given in the APG website (Stevens, 2001 onwards), the largest family is Orchidaceae (27,800 species/880 genera). Other dominant families are: Asteraceae (23,600 species / 1620 genera), Fabaceae (19,560/745), Rubiaceae (13,150 /611) and Poaceae (11,337/ 707).

Perusal of the literature has revealed that of the 413 families, 259 are represented in India. The distribution pattern of the families indicate that 5 families are endemic to Madagascar, 4 to Cape Province of South Africa and Chile each, 3 to New Caledonia, one family each for Somalia, Tasmania, China, Fiji islands and Mexico. It is interesting to note that 24 families are endemic to Australian continent and surrounding islands. African continent with Madagascar is an exclusive home for 17 families.

A formal classification of the land plants that is compatible with the APG III classification was proposed by Chase & Reveal (2009). For detailed information on orders and family delimitations, readers are advised to consult APWeb (Stevens, 2001 onwards) and for molecular and allied datasets used for separation of different clades, orders and families in APG, consult APG II (APG II, 2003).

APG III *vis-à-vis* BENTHAM AND HOOKER CLASSIFICATION

An attempt has been made to compare the positions of families as treated in Bentham and Hooker's classification with that of 413 families of APG III. Thirty five families, (mostly monotypic) have been described after the publication of *Genera Plantarum* (Bentham and Hooker, 1862-83). Significant changes in APG III treatment of families *vis-à-vis* Bentham and Hooker's system include the following. Liliaceae *s.l.* is split into 14 families and many of them are transferred to Asparagaceae. Molluginaceae and Gisekiaceae are recognized separately from Aizoaceae. Euphorbiaceae *s.l.* is split into Euphorbiaceae *s.s.*, Phyllanthaceae, Picrodendraceae and Putranjivaceae. Genera *Sopubia* and *Striga* (Scrophulariaceae) are included in Orobanchaceae; *Hydrocotyle* (Apiaceae) is included in Araliaceae. Bombacaceae, Sterculiaceae and Tiliaceae are merged with Malvaceae; Asclepiadaceae with Apocynaceae; Avicenniaceae with Acanthaceae; Barringtoniaceae with Lecythidaceae; Chenopodiaceae with Amaranthaceae; Cochlospermaceae with Bixaceae; Cotylaceae with Betulaceae; Cuscutaceae with Convolvulaceae; Viscaceae with Santalaceae; Myrsinaceae with Primulaceae; Rhododendraceae and Vacciniaceae with Ericaceae; Lobeliaceae with Campanulaceae; Valerianaceae with Caprifoliaceae. Many genera of Scrophulariaceae and Verbenaceae are merged with Plantaginaceae and Lamiaceae respectively (Refer to Table 2 for details). It is interesting to note that APG like that of Bentham and Hooker's system considered Papilionaceae, Caesalpiniaceae and Mimosaceae as subfamilies of Fabaceae *viz.*, Faboideae, Ceasalpinioideae and Mimosoideae.

LAPG & LAPG III

Haston *et al.* (2007), developed a linear sequence of families (called as LAPG) based on APG II classification and provided a list of 479 families. Haston *et al.* (2009) revised LAPG for the new APG III classification as LAPG III and considered 413 families. Although the methodology followed has been questioned by Hawthorne *et al.* (2008), it is concluded

that in the absence of any obviously better way of generating a linear sequence from a phylogenetic tree, APG III can be considered a viable system with options open to modify the methodology to ensure stability. It is pertinent to note that many European herbaria have agreed to adopt LAPG. The LAPG sequence has been accepted by RBG Kew, RBG Edinburgh, the Natural History Museum (London), the Musée National d'Histoire Naturelle (Paris), Conservatoire et Jardin Botaniques (Geneva) and the National Herbarium Nederland (Leiden, Utrecht and Wageningen) to re-arrange their herbarium collections.

In APG III, families are alphabetically arranged in clades. In LAPG, families within the clades are reorganized. With respect to unplaced orders and families at the beginning, orders sequence in LAPG is similar to that of APG III, but families are re-organised. In Magnoliid clade, Magnoliales are followed by Laurales, *vice-versa* in APG III. In the clade Monocots, orders are in the same sequence as that of APG III. In Commelinids, Zingiberales are followed by Poales, *vice-versa* in APG III. Unplaced Dasypogonaceae is retained in the same clade, but kept in between Zingiberales and Poales, which were kept at the beginning in APG III. Ceratophyllales and Ceratophyllaceae position as probable sister of eudicots is unchanged. In Eudicots, orders are in the same sequence like that of APG III. Even unplaced Sabiaceae is retained in the same position between Ranunculales and Proteales. In Core Eudicots, orders are in the same sequence like that of APG III. Dilleniaceae, the unplaced family is retained in the same position after Gunnerales. Cynomoriaceae considered as taxa of uncertain position and kept at the end in APG III is included in core eudicots in LAPG. There is no change in Rosids taxa. In Fabids and Malvids, sequence of orders is changed. In Asterids, sequence of orders is unchanged. In Lamiids, sequence of orders is changed. Of the 5 unplaced families kept at the beginning in APG III, 3 families are kept at the beginning and other two placed between Gentianales and Solanales in LAPG.

Currently some of the problems of placement of families and genera have been resolved in the latest update of APG which can be consulted on <http://www.mobot.org/MOBOT/research/APweb>.

Table1 : ABSTRACT OF APG CLASSIFICATION

Clade/ Group (No. of orders/families)	Orders (No. of families)
-	Unplaced Orders Amborellales (1) ; Nymphaeales (3) Austrobaileyales (3); Chloranthales (1)
MAGNOLIIDS (4/20)	Canellales (2) ; Piperales (5); Laurales (7) Magnoliales (6)
MONOCOTS (7/47)	Acorales (1) ; Alismatales (13); Petrosaviales (1); Dioscoreales (3); Pandanales (5) Liliales (10) ; Asparagales (14)
COMMELINIDS (4/31)	Unplaced family-Dasyopogonaceae Arecales (1) ; Commelinales (5); Poales (16) Zingiberales (8)
PROBABLE SISTER OF EUDICOTS (1/1)	Ceratophyllales (1)
EUDICOTS (4/14)	Ranunculales (7) ; Unplaced family- Sabiaceae Proteales (3) ; Trochodendrales (1); Buxales (2)
CORE EUDICOTS (2/17)	Gunnerales (2) ; Unplaced family- Dilleniaceae Saxifragales (14)
ROSIDS (1/1)	Vitales (1)
FABIDS (8/73)	Zygophyllales (2); Celastrales (2); Oxalidales (7); Malpighiales (35); Cucurbitales (7); Fabales (4); Fagales (7); Rosales (9)
MALVIDS (11/ 102)	Geraniales (3); Myrtales (9); Crossosomatales (7); Picramniales (1); Huerteales (3); Brassicales (17) Malvales (10); Sapindales (9); Berberidopsidales (2); Santalales (7); Caryophyllales (34)
ASTERIDS (2/28)	Cornales (6); Ericales (22)
LAMIIDS (4/40)	Unplaced families: Boraginaceae, Vahliaceae, Icacinaceae, Metteniusaceae, Oncothecaceae Garryales (2); Gentianales (5); Lamiales (23) Solanales(5)
CAMPANULIDS (7/29)	Aquifoliales (5); Asterales (11); Escalloniales (1); Bruniales (2); Paracryphiales (1); Dipsacales (2); Apiales (7)
TAXA OF UNCERTAIN POSITION	2 families: Apodanthaceae and Cynomoriaceae 3 genera : <i>Gumillea</i>, <i>Petenaea</i> (possibly Malvales) and <i>Nicobariodendron</i>

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