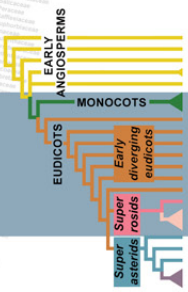
PLANT GATEWAY'S

The Global Flora

A practical flora to vascular plant species of the world



SPECIAL EDITION

Introduction

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INTRODUCTION

Introducing *The Global Flora*
The phylogeny of angiosperms poster

January 2018

The Global Flora

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Cover image: Simplified angiosperm phylogeny © James Byng

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Introducing *The Global Flora,* a global series of botany

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Species Plantarum by Linnaeus (1753) contained 5,940 species of plants, including all known species then known globally. Since its publication 264 years ago, the exploration of plant diversity across the planet has led to approximately 374,000 known, described and accepted plant species (Christenhusz & Byng, 2016). This number increases by approximately 2000 additional new species each year, despite the slow but steady decrease in the number of active herbarium taxonomists focused on monography. Current estimates suggest that at least twenty percent of all botanical diversity still remains to be discovered, analysed (or re-analysed), described and named.

Herbaria are exceptionally rich sources of botanical information. They house voucher specimens used for anatomical, biogeographical, chemical, molecular, morphological, palynological and taxonomical studies. Type specimens, which permanently link a scientific name to a physical specimen, effectively are the "birth certificates" of each species, and are amongst the most important specimens in each herbarium. Herbarium specimens collectively provide critical baseline data for where and when a species occurred, and they can be used to evaluate population increases or declines. Thus herbarium collections provide the physical evidence for much of our botanical knowledge.

An ongoing and acute problem in taxonomy is that large numbers of specimens in nearly all herbaria are either unidentified or identified incorrectly (e.g. Bebber *et al*., 2010; Goodwin *et al*., 2015). This does not reflect incompetence or negligence on the part of botanists, but rather a dearth of active taxonomists (Uno, 2009) and low (and declining) levels of funding for basic research (Dalton *et al.,* 2003; Agnarsson & Kuntner, 2007; Ahrends *et al.*, 2010). Taxonomic studies are never-ending as new species are described, new specimens are collected and need identifying and older treatments need to be updated following new findings in nomenclature, taxonomy and evolutionary botany.

Fortunately, some positive developments are occurring in systematics given the advent of digitial technologies. The recent acceptance of electronic publication in the *International Code of Nomenclature for Algae, Fungi and Plants* has significantly expedited species discovery and the solving of associated nomenclatural issues (McNeill *et al.*, 2012; Christenhusz & Byng, 2016). But while digital technologies and electronic publication are helping to speed up some aspects of taxonomy, fewer treatments having a global taxonomic focus are being produced. Those who must rely heavily on these treatments, such as ecologists, conservation biologists, and invasive species biologists often are fully aware that no reliable and current source of current taxonomic information exists at the global level for many groups of plants.

Plant Gateway is working on various higher-level classifications and overviews of vascular plants (e.g. Christenhusz *et al*., 2011; Christenhusz & Chase, 2014; Byng, 2014, 2015; APG IV, 2016; Christenhusz & Byng 2016; Christenhusz *et al*., 2017; Byng *et al*., 2018). In this framework, we are introducing *The Global Flora*, a new international serial for botanical taxonomy, to provide accepted species-level classifications for all vascular plant families based on available or generated molecular data and re-examining the literature and herbarium specimens in major herbaria. The goal is to provide a current, balanced and practical taxonomy reflecting evolutionary relationships.

The Global Flora will be available in print and online versions and include three series: (A) Angiosperms (following APG IV, 2016); (B) Lycopods, Ferns and Gymnosperms (classification following Christenhusz *et al*., 2017); and (C) special editions. The first two series will only treat monophyletic taxa on a global scale (e.g. family, subfamily, tribe, genus or section). The content and format of each taxonomic treatment in the first two series will vary depending on the group, and interested authors should consult the first few published treatments for guidance. The special editions series aims to make significant contributions to the body of plant systematic knowledge and typically will be of a global botanical scope.

The Global Flora will be published frequently and at regular intervals. It will be amply illustrated and should appeal to many different users, including ecologists, conservationists, gardeners and other plant enthusiasts in the applied sciences, as opposed to appealing solely to practicing taxonomists. As important new evidence becomes available updates and revisions to already published treatments will be allowed to make the treatments current and dynamic. Unlike other journals and flora serials, *The Global Flora* will share royalties with authors and compensate reviewers and editors for their respective duties. This is important for maintaining momentum, because relatively few institutions provide time and funds for researchers to do this time-consuming, yet crucially important work. An unspoken consensus of many taxonomists is that the

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historical lack of remuneration for this type of research is a primary reason that taxonomy does not progress more rapidly.

In addition, we believe that some of the funds generated from taxonomic work should be retained within the taxonomic community. For reviewers and contributors who are unable to accept royalties as part of their positions, or who choose to waive them altogether, the royalties will be transferred to a *Global Flora Small Grants Fund* to allow future contributors to undertake herbarium visits and generate data for future treatments in *The Global Flora*. In return for a fee, authors may opt for their taxonomic treatments to be open-access, which will cover editorial costs, and the remainder of which shall be added to the *Global Flora Small Grants Fund.* All special edition issues will be open-access.

We hope our readers enjoy and support *The Global Flora* in its initial stages. An Editorial Board is being formed as our first issues appear. We also hope that the contents of *The Global Flora* will provide significant contributions to help achieve Target 1 of the Global Strategy for Plant Conservation established for 2020, and we hope the series will grow towards a global and complete coverage of the vascular plants of the world.

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The phylogeny of angiosperms poster: a visual summary of APG IV family relationships and floral diversity

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Abstract

This article provides a visual overview of the relationships of all angiosperm families (following APG IV). The poster lists important characters for major grades and clades and these are illustrated with flower images of 269 plant families. It is presented to provide a useful educational tool. The scientific names and photo accreditation of each image are listed.

Keywords

Angiosperms – Flower images – Phylogeny – Poster – Taxonomy – Teaching

Background

It is widely accepted in many countries that courses, practicals and lectures focusing on plant taxonomy have been in decline during the last few decades (e.g. Hershey, 1996; Woodland, 2007; Drea, 2011; Uno, 2011). Many undergraduate biology students find currently that learning basic classification and relationships of plants are taught often during a single practical, which results in many young biologists graduating with little understanding of botanical diversity and without having sufficient identification and taxonomic skills. Current students know far less about plant family relationships than before, despite scientific insights being better.

There has been a molecular revolution in the field of plant taxonomy during the last 25 years, where thousands of phylogenetic trees have been generated using molecular sequences from thousands of plant species. Our understanding of higher-level classification of angiosperms have improved substantially, which have led to four versions of the widely used and primarily molecular based Angiosperm Phylogeny Group (APG) classification (APG 1998; APG II 2003; APG III 2009; APG IV 2016). Unexpected relationships, like that of Nelumbonaceae with Proteaceae, were uncovered and circumscriptions for several families (e.g. Malvaceae, Molluginaceae, Portulacaceae, Salicaceae, Sapindaceae, Scrophulariaceae) have substantially changed with molecular data and this often makes much of the available literature difficult to use for teaching, although several new works aiding in the teaching of plant taxonomy, identification and economic botany have recently been published following the modern classifications like APG (e.g. Byng, 2014; Christenhusz *et al*., 2017). However, many of the plant taxonomic works used for teaching are too technical for beginners or too regionally focused. Because usually only a small subset of plant families is taught students get confused or despair in the greater diversity they may discover when they visit gardens or greenhouses where cultivated plants are grown from all around the world.

In *The phylogeny of angiosperms poster* (Figure 1) we present a global overview of the relationships of all 416 families in the 64 orders following the APG IV classification (Figures 1, 2, 3, 5, 8, 10, 12, 14, 16, 19, 21, 23, 26). Phylogenetic trees that include all APG IV

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families are few, because the APG classifications were based on a number of independent papers that treat parts of the angiosperms, and the one presented in the poster is discussed in more detail in Byng *et al*. (in prep.), notably concerning the orders Ceratophyllales and Dilleniales.

The poster includes 269 flower images (Figures 1, 4, 6, 7, 9, 11, 13, 15, 17, 18, 20, 22, 24, 25, 27) showing a diverse range of floral morphology. We aim to show this diversity to enthuse students and teachers and anyone with an interest in plants. It provides a visually stunning tool for education and it will be a practical resource for teaching introductory and advanced classes in botany. We hope it will inspire students to pursue a future career in botany.

Acknowledgements

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Appendix 1

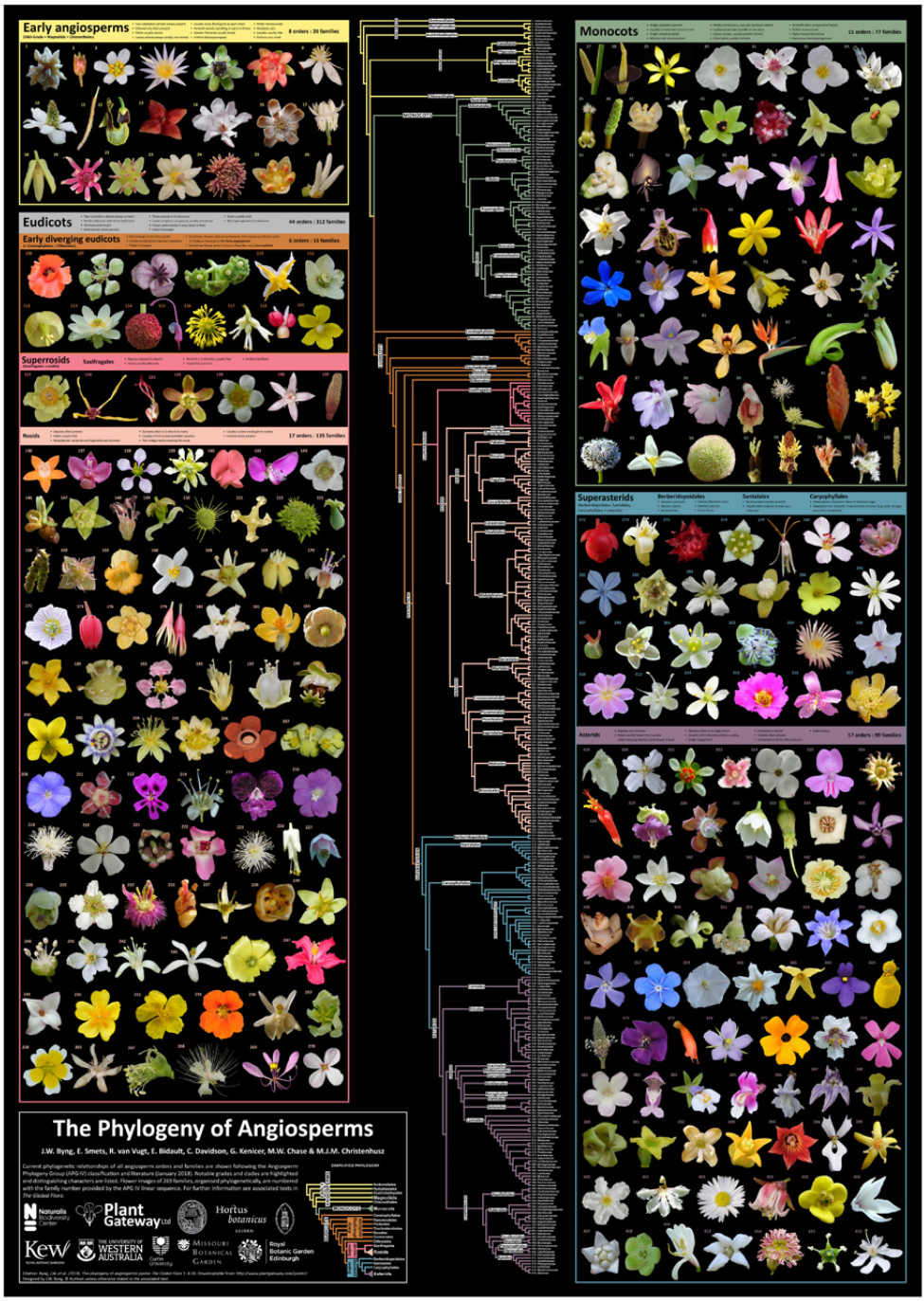

Figure 1: Overview of The phylogeny of angiosperms poster.
Full download available from: http://www.plantgateway.com/poster/

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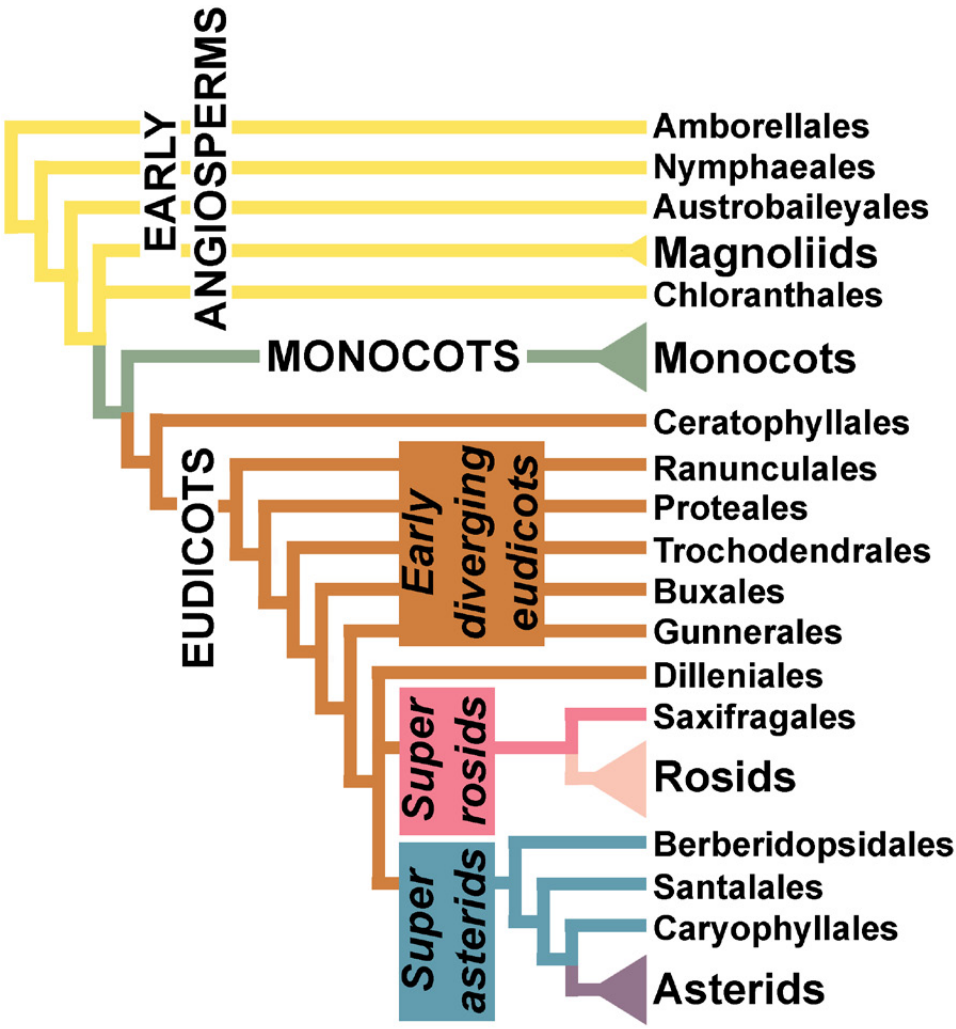

Figure 2: A simplified phylogeny of angiosperms.

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Early angiosperms

8 orders : 26 families
(ANA-grade + magnoliids + Chloranthales)

Two cotyledons almost always present
Ethereal oils often present
Leaves almost always simple, net-veined
Usually many floral parts to each whorl
Perianth usually spiralling or parts in threes
Stamen filaments usually broad
Anthers tetrasporangiate
Pollen monosulcate
Nectaries rare
Carpels usually free
Embryo very small

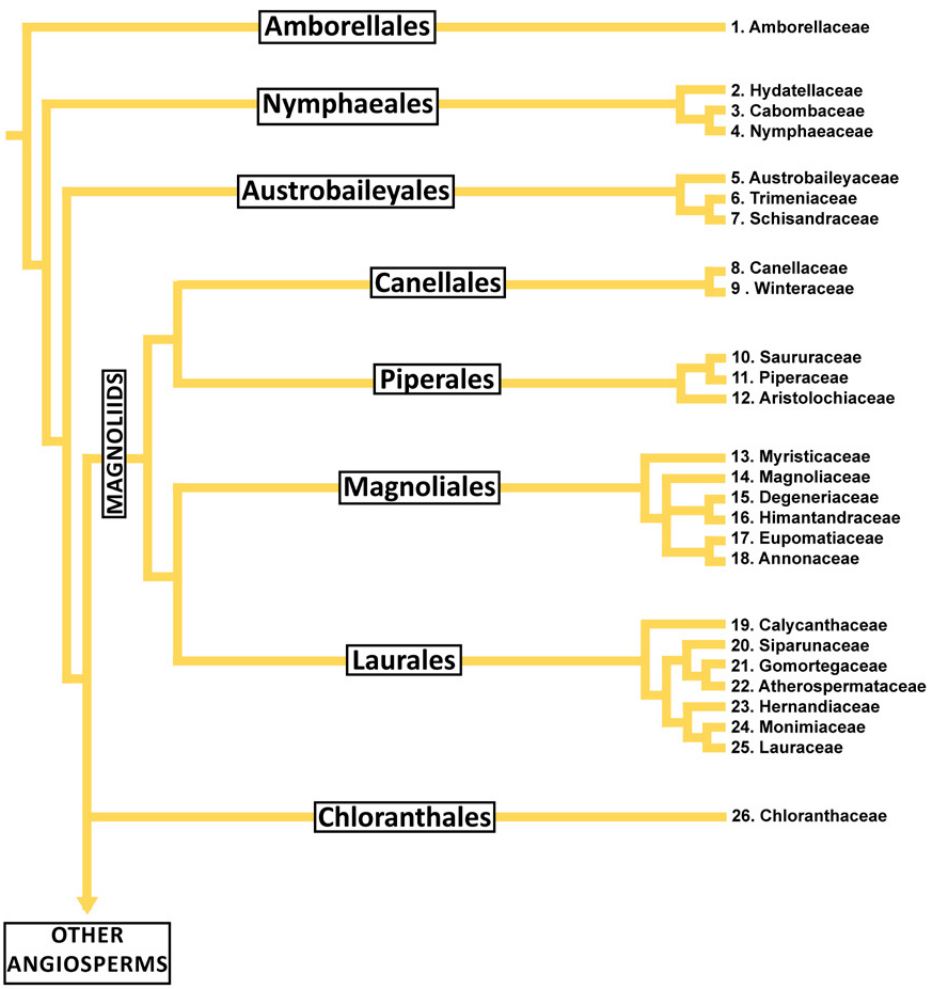

Figure 3: Diagnostic characters and relationships of early angiosperms.

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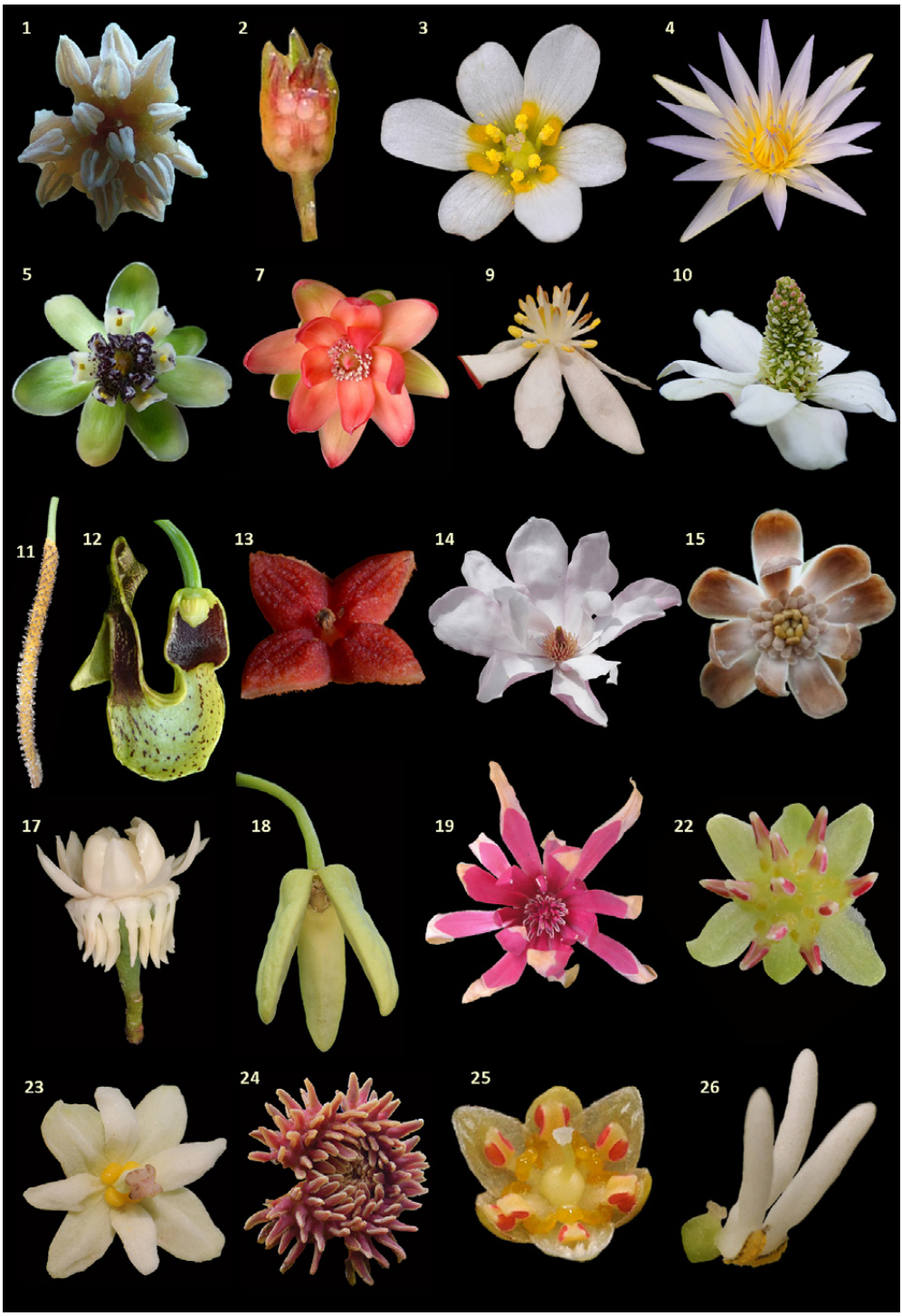

Figure 4: Floral images of Amborellales (family 1), Nymphaeales (2-4), Austrobaileyales (5-7), Canellales (9), Piperales (10-12), Magnoliales (13-18), Laurales (19-25) and Chloranthales (26).

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Monocots

11 orders : 77 families
(basal monocots + lilioid + commelinids)

Single cotyledon present	Mostly herbaceous, vascular cambium absent	Perianth often composed of tepals
Usually a short-lived primary root	Scattered vascular bundles in the stem	Pollen monosulcate
Single adaxial prophyll	Leaves simple, usually parallel-veined.	Styles frequently hollow
Ethereal oils rarely present	Floral parts usually in threes	Successive microsporogenesis

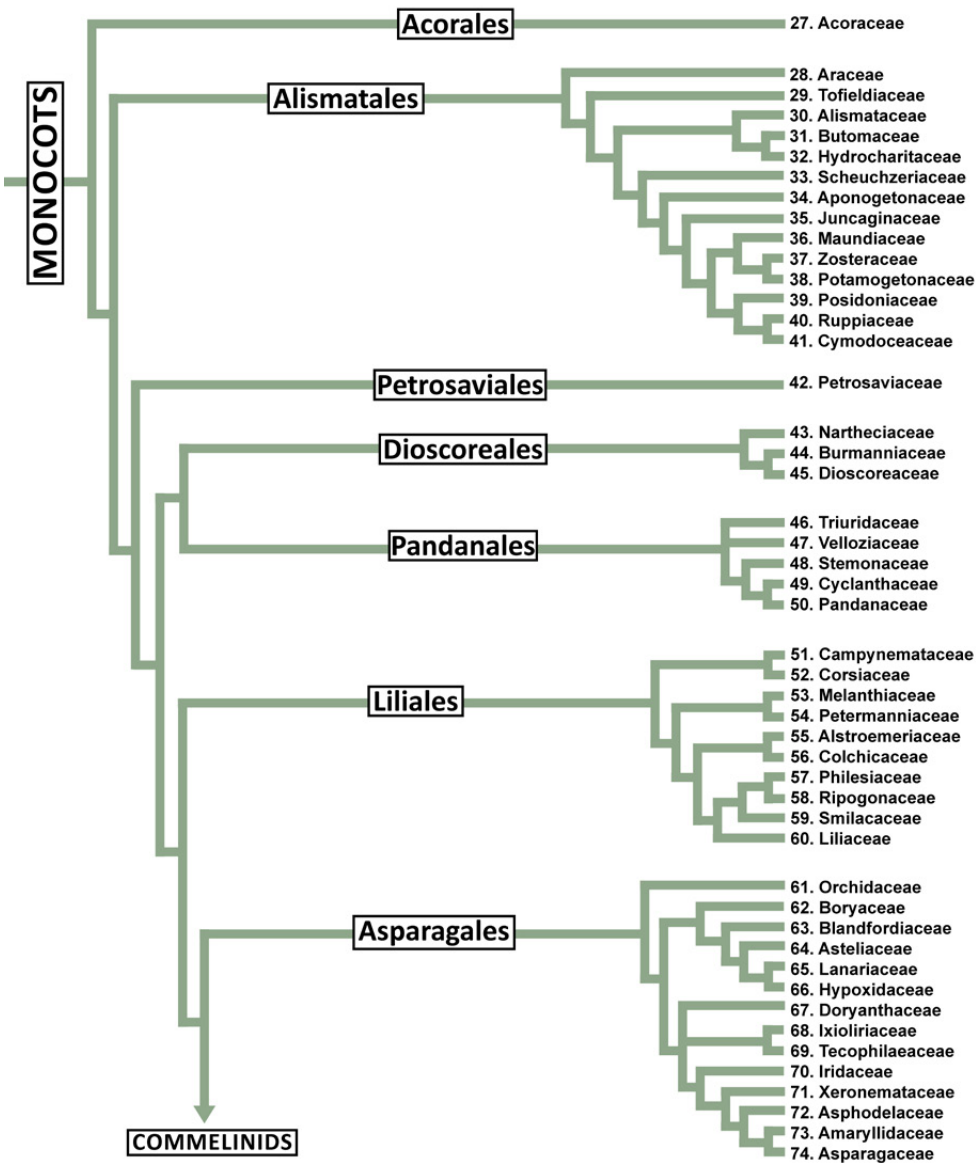

Figure 5: Diagnostic characters and relationships of monocots.

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Figure 6: Floral images of Acorales (family 27), Alismatales (28-38), Petrosaviales (42), Dioscoreales (44-45), Pandanales (46-50) and Liliales (52-57).

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Figure 7: Floral images of Liliales (families 59-60) and Asparagales (61-74).

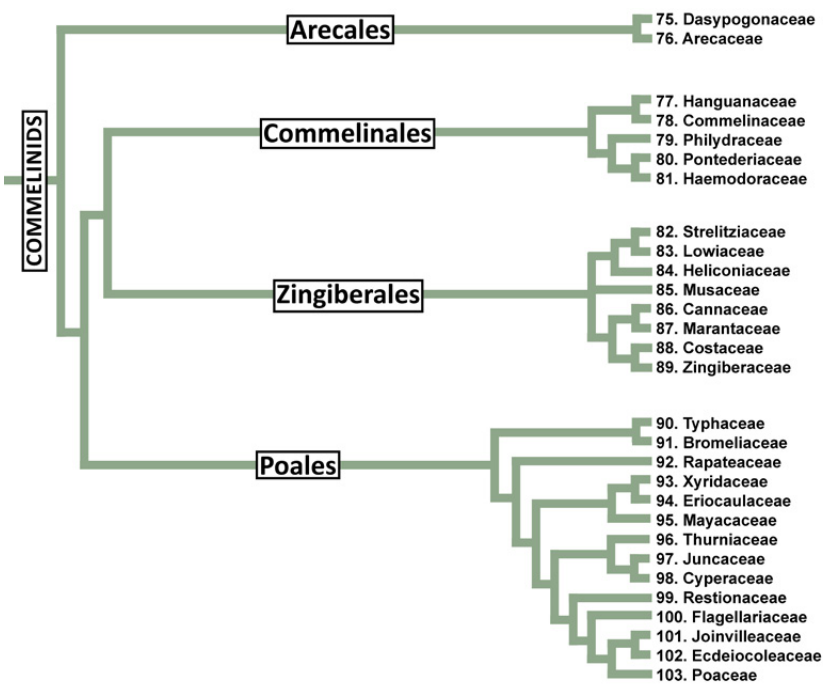

Figure 8: Relationships of commelinid monocots.

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Figure 9: Floral images of the Arecales (family 76), Commelinales (78-81), Zingiberales (82-89) and Poales (90-103).

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Eudicots

45 orders : 313 families
(early diverging eudicots + superrosids + superasterids)

Two cotyledons almost always present
Nodes trilacunar with three leaf traces
Stomata anomocytic
Ethereal oils rarely present
Plants woody or herbaceous
Leaves simple or compound, usually net-veined
Flower parts mostly in twos, fours or fives
Microsporogenesis simultaneous
Styles usually solid
Pollen tricolpate

Early diverging eudicots

7 orders : 17 families
+ Ceratophyllales & Dilleniales

Morphological transition grade
Exhibit ancestral and derived characters
Pollen tricolpate
Sometimes flowers with many stamens, free carpels and flower parts in threes or many parts like ***Early angiosperms***
Sometimes flower parts in fours or fives like many ***Core eudicots***

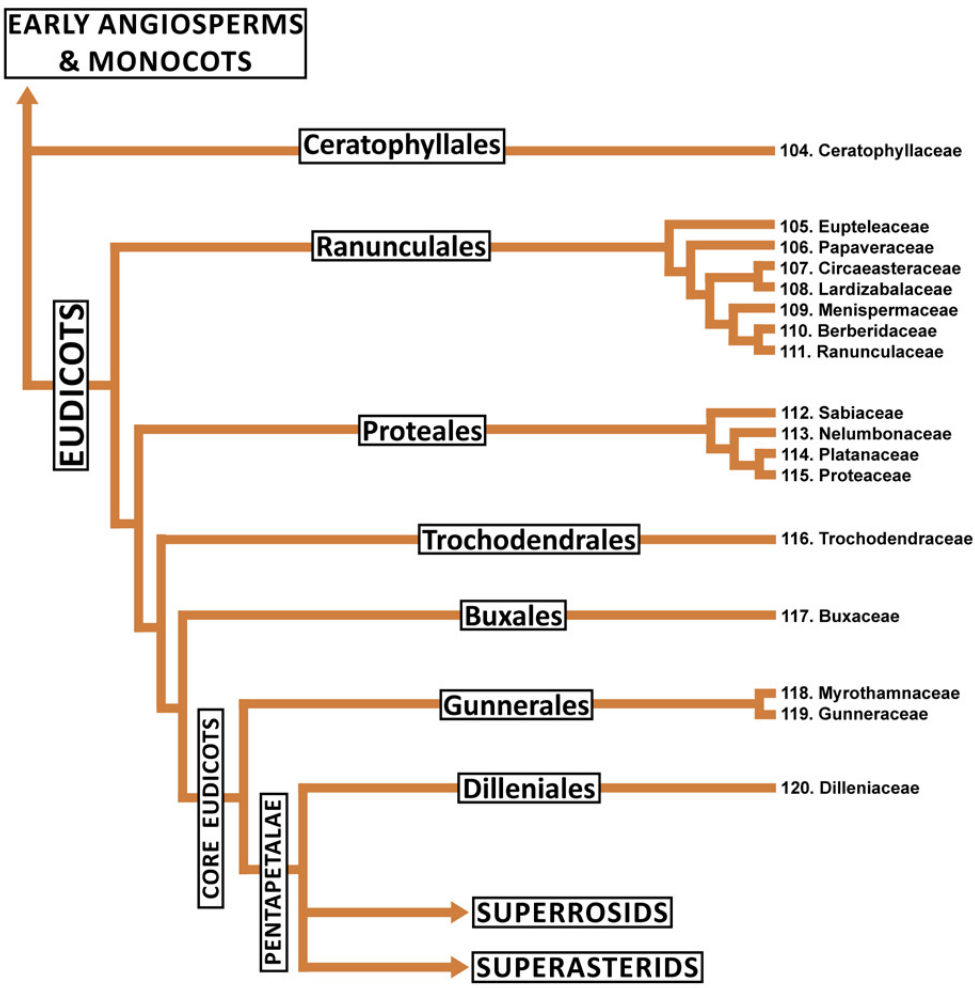

Figure 10: Diagnostic characters and relationships of early diverging eudicots.

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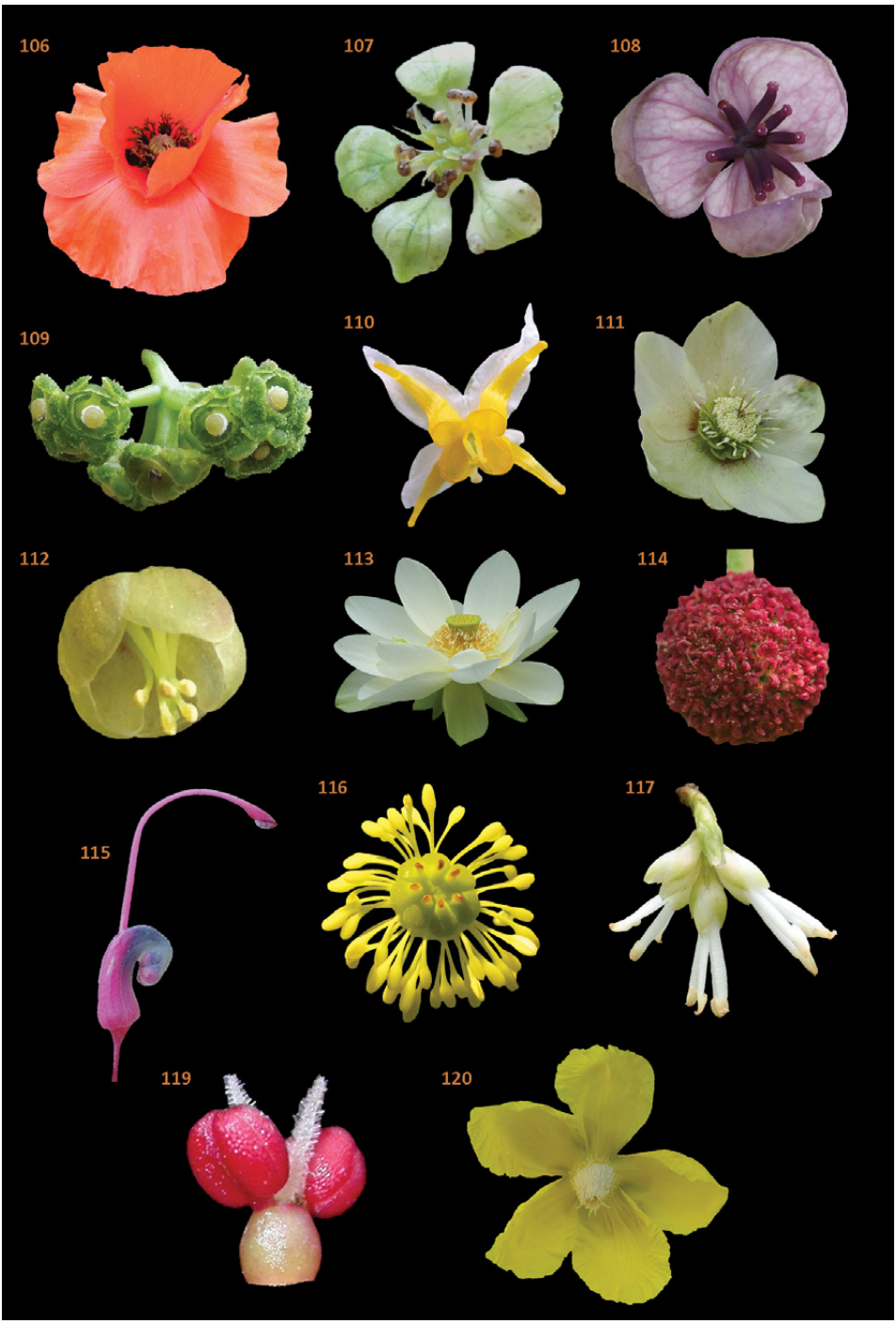

Figure 11: Floral images of Ranunculales (families 106-111), Proteales (112-115), Trochodendrales (116), Buxales (117), Gunnerales (119) and Dilleniales (120).

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Superrosids

18 orders : 150 families
(Saxifragales + rosids)

Rosids

17 orders : 135 families
(Vitales + fabids + malvids)

- Stipules often present (about 65% of families)
- Petals usually free (about 97%)
- Receptacular nectaries and hypanthia are common
- Stamens often in 2 whorls to many (about 58%)
- Thick (crassinucellate) nucellus (about 92%)
- Two integuments covering the ovule (about 95%)
- Endosperm nuclear (about 95%)
- Iridoids rarely present

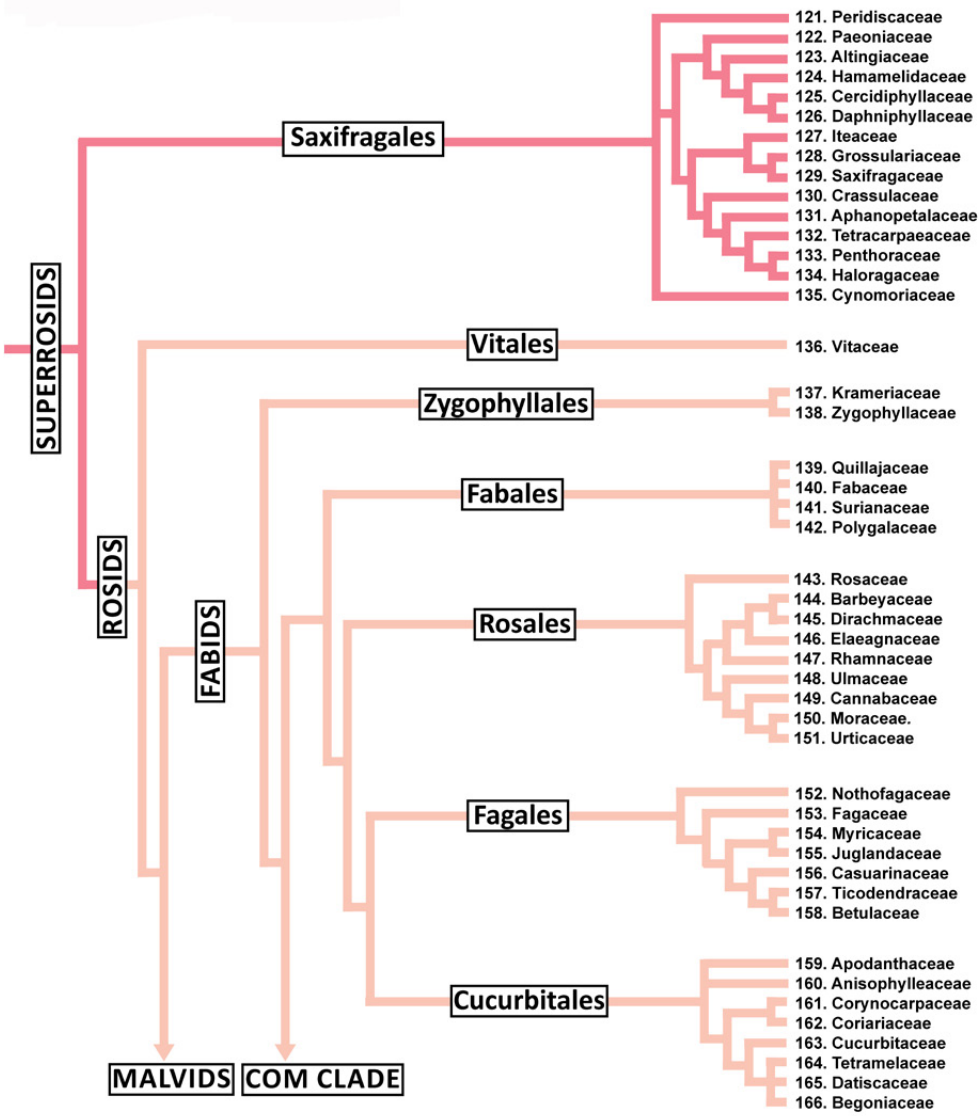

Figure 12: Diagnostic characters and relationships of Saxifragales and rosids.

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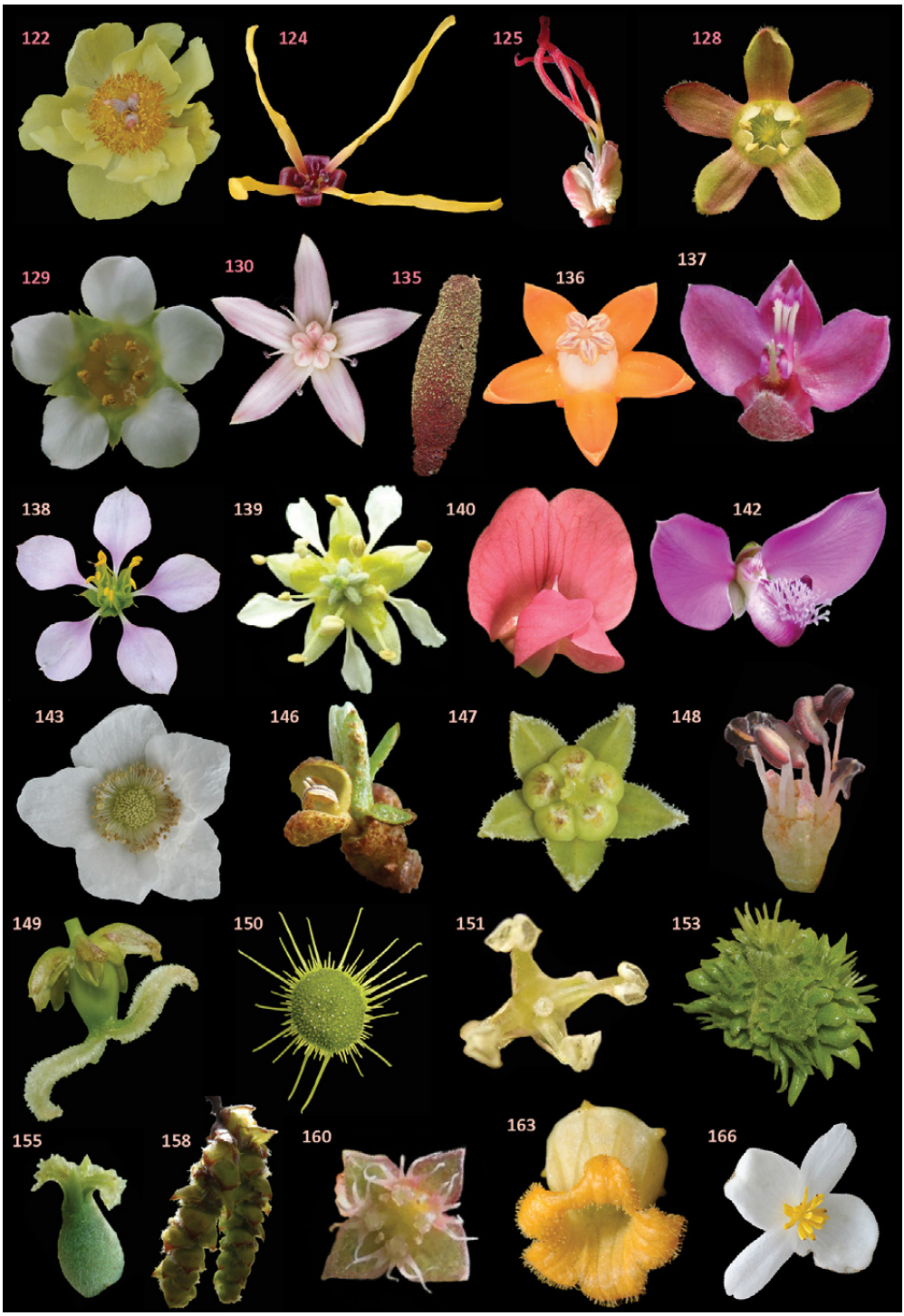

Figure 13: Floral images of Saxifragales (families 122-135), Vitales (136), Zygophyllales (137-138), Fabales (139-142), Rosales (143-151), Fagales (153-158) and Cucurbitales (160-166).

ISSN 2398-6336 eISSN 2398-6344
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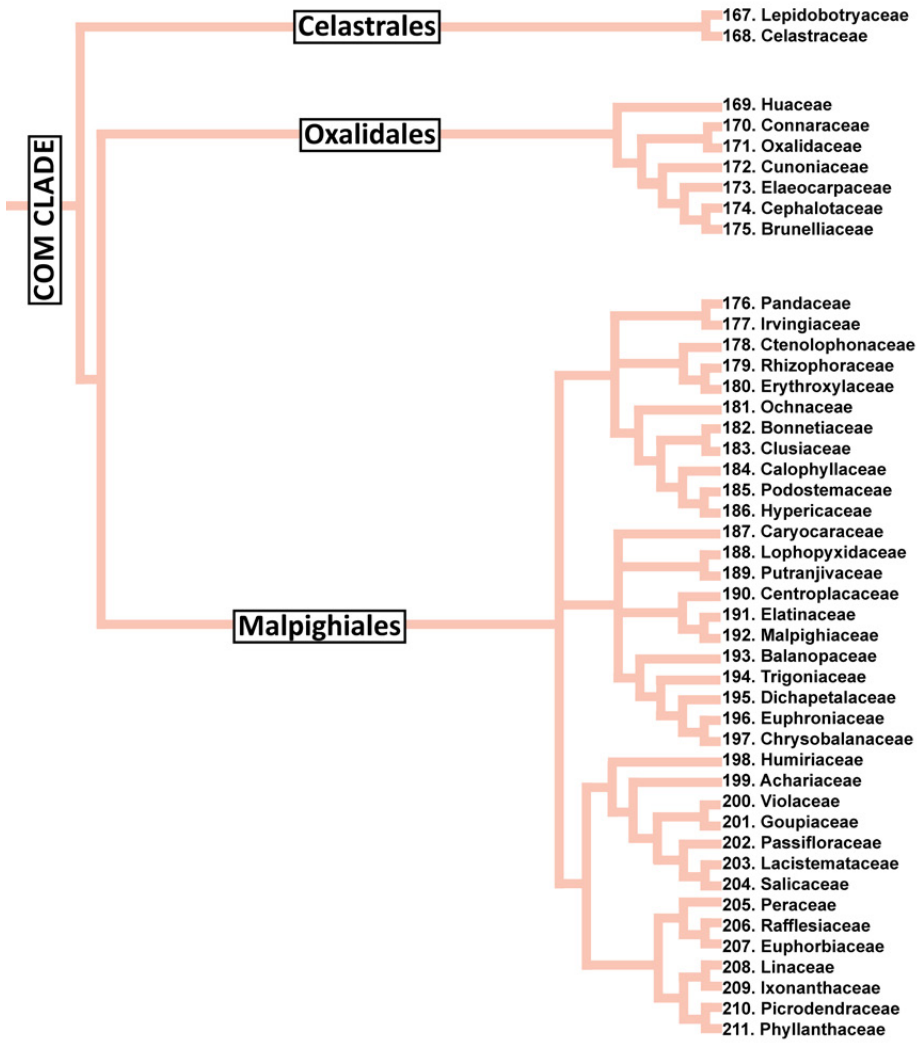

Figure 14: Relationships of the COM clade of rosids.

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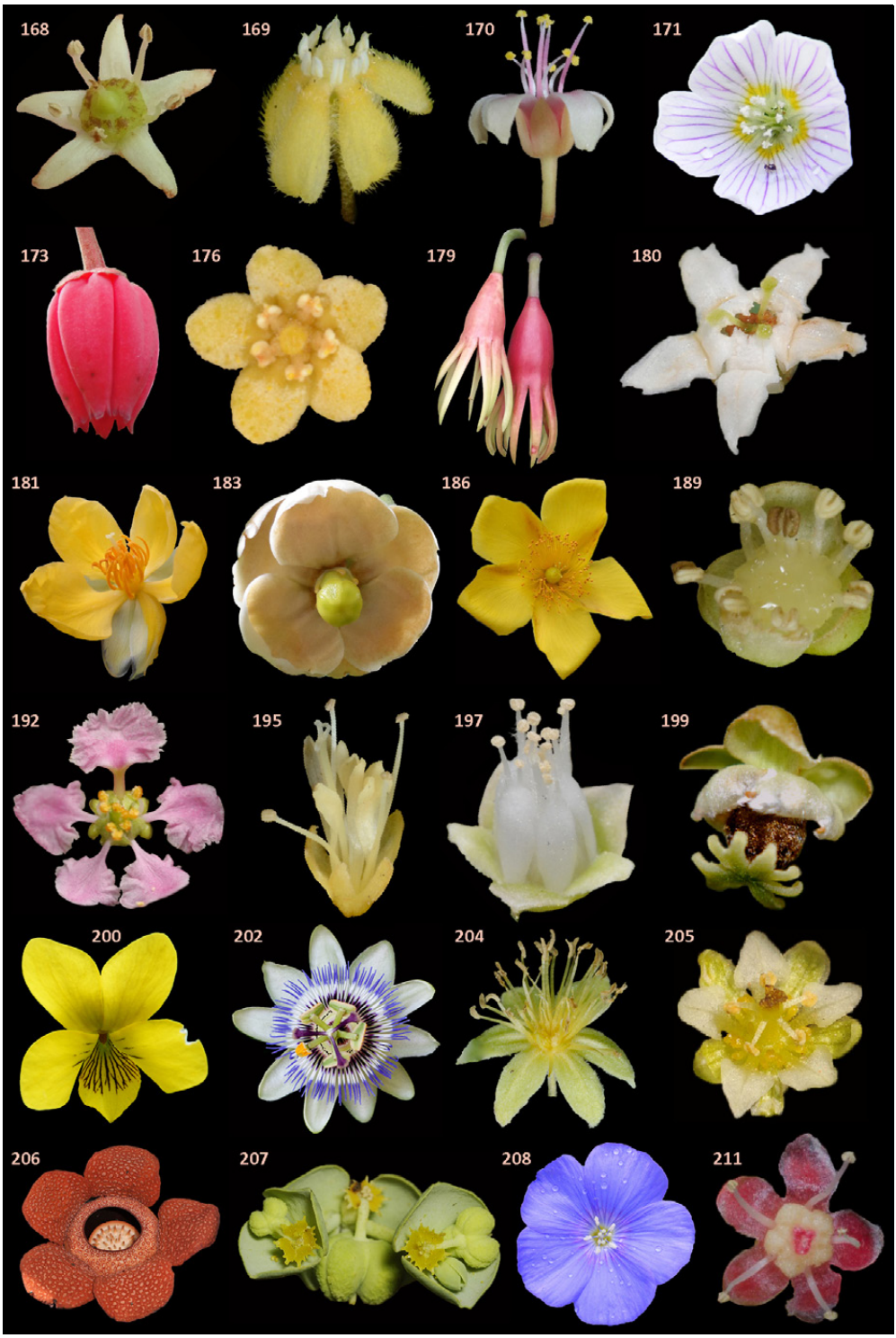

Figure 15: Floral images of Celastrales (family 168), Oxalidales (169-173) and Malpighiales (176-211).

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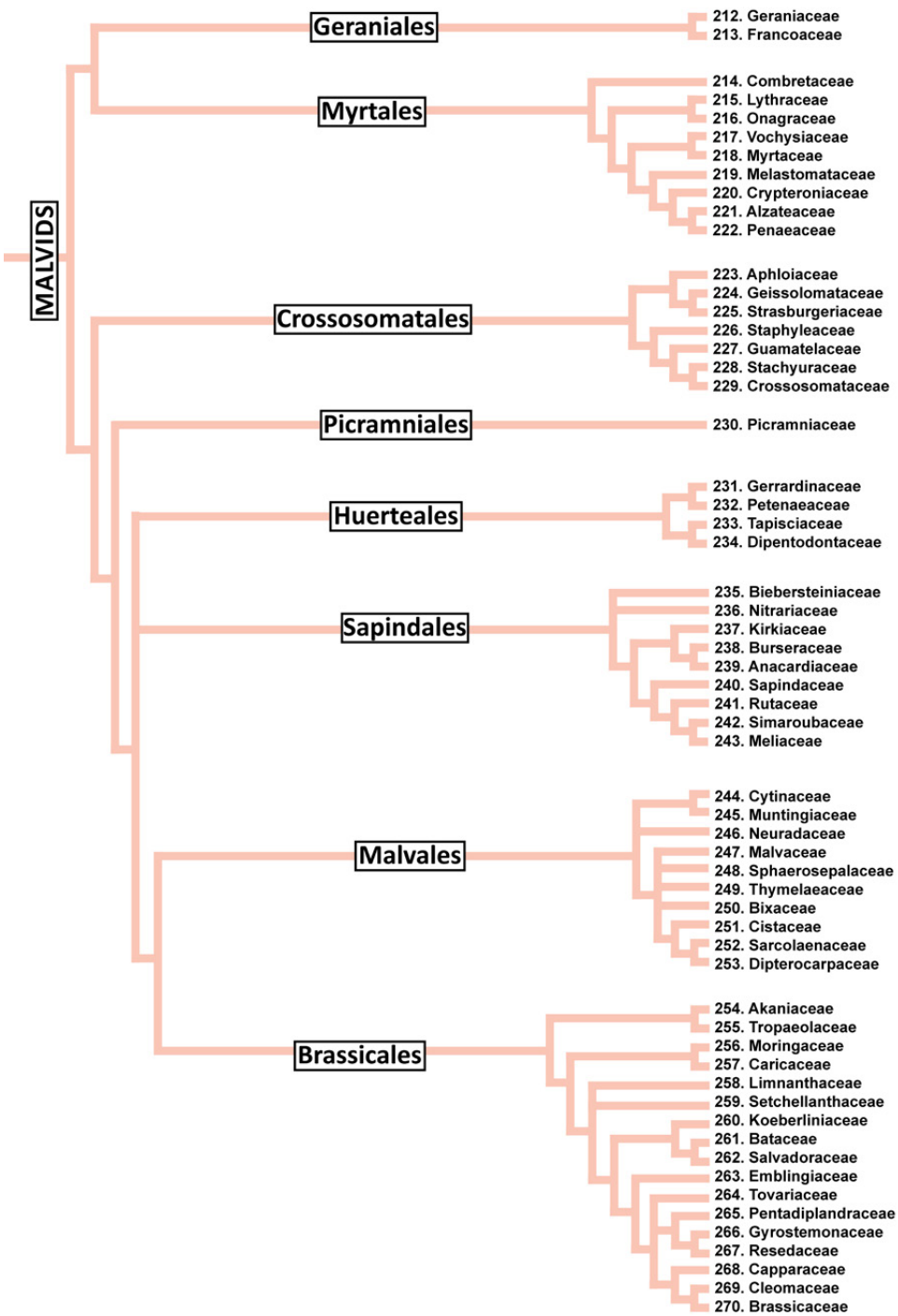

Figure 16: Relationships of malvid rosids.

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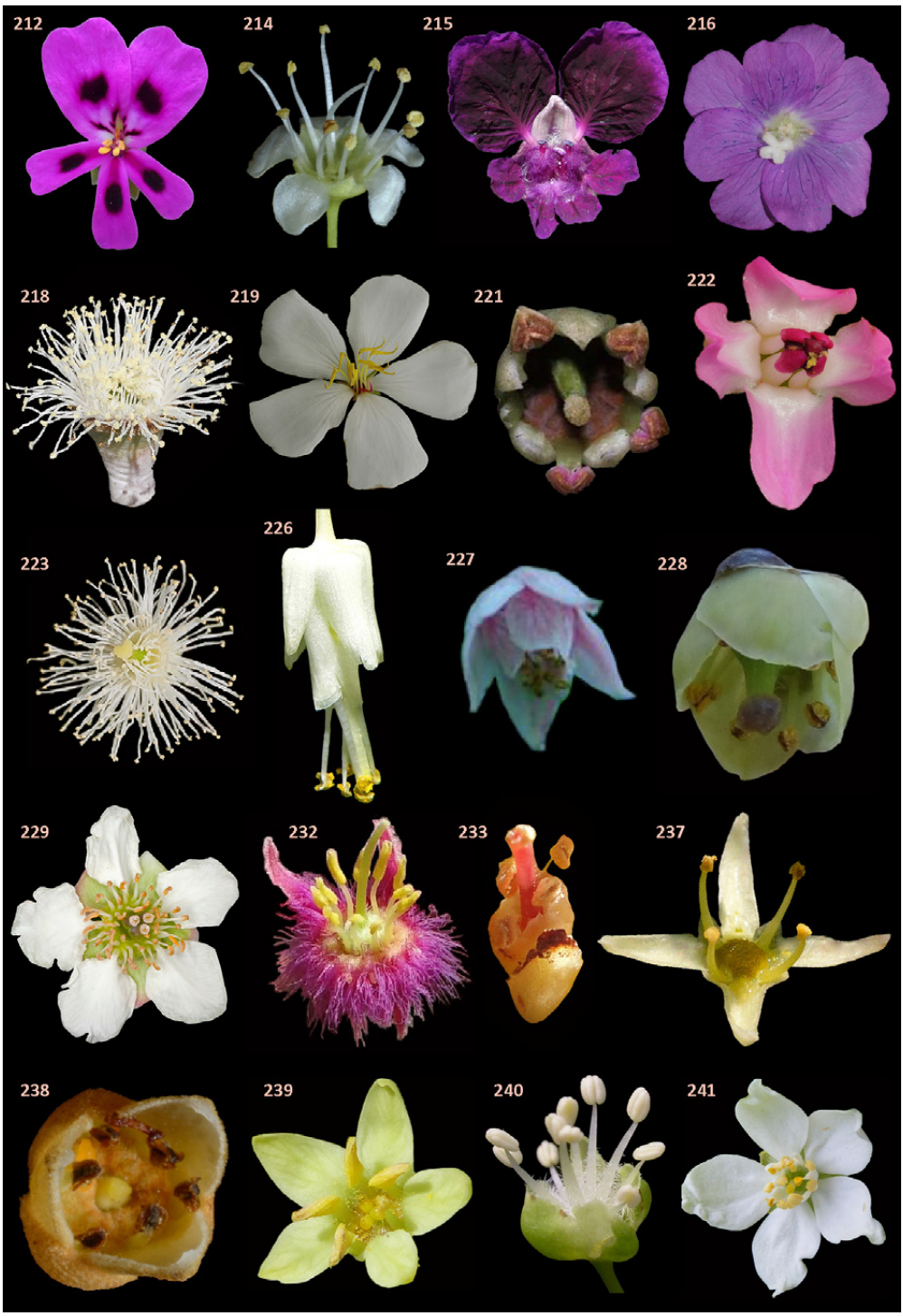

Figure 17: Floral images of Geraniales (family 212), Myrtales (214-222), Crossosomatales (223-229), Huerteales (232-233) and Sapindales (237-241).

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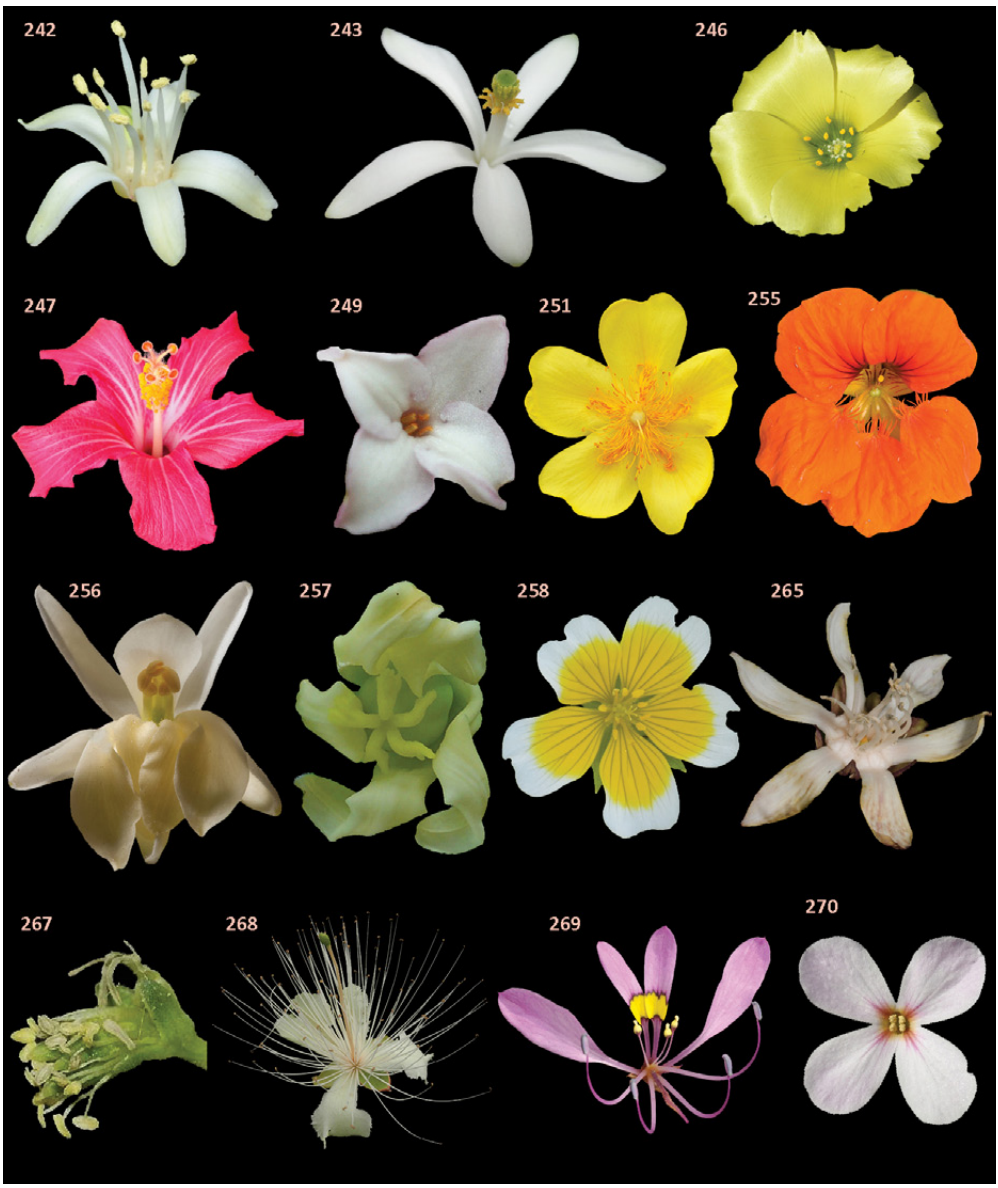

Figure 18: Floral images of Sapindales (families 242-243), Malvales (246-251) and Brassicales (255-270).

Published online 14 January 2018

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Superasterids

20 orders : 146 families
(Berberidopsidales + Santalales + Caryophyllales + asterids)

Berberidopsidales

Stomata cyclocytic
Stipules absent
Perianth free
Stamen filaments stout
Ovaries superior
Fruits fleshy

Santalales

Plants predominantly parasitic
Sepals often reduced, known as a 'calyculus'

Caryophyllales

Petals absent, if present likely of staminal origin
Adaptations to 'stressful' environments common (e.g. arid, nitrogen poor soils, halophytic)

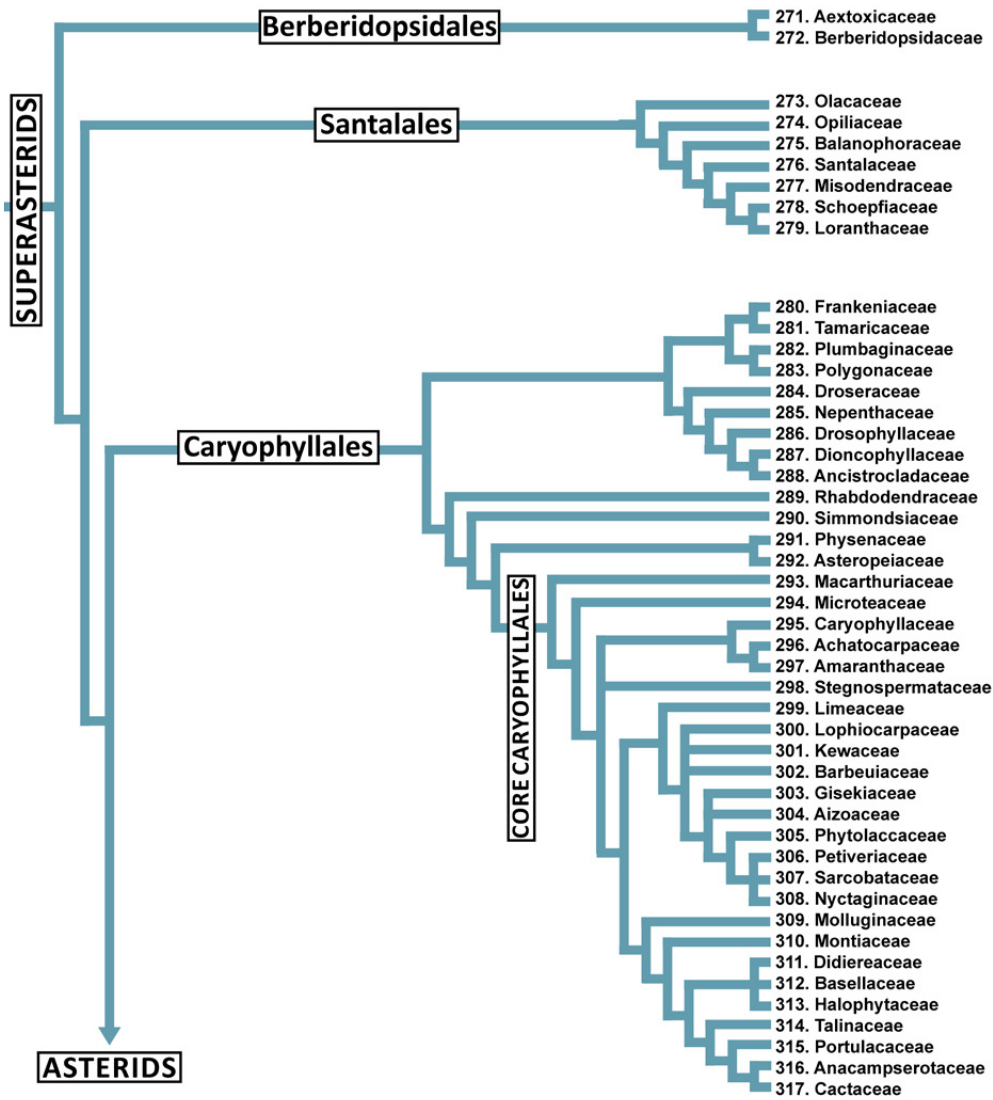

Figure 19: Diagnostic characters and relationships of Berberidopsidales, Santalales and Caryophyllales.

Published online 14 January 2018

ISSN 2398-6336 eISSN 2398-6344
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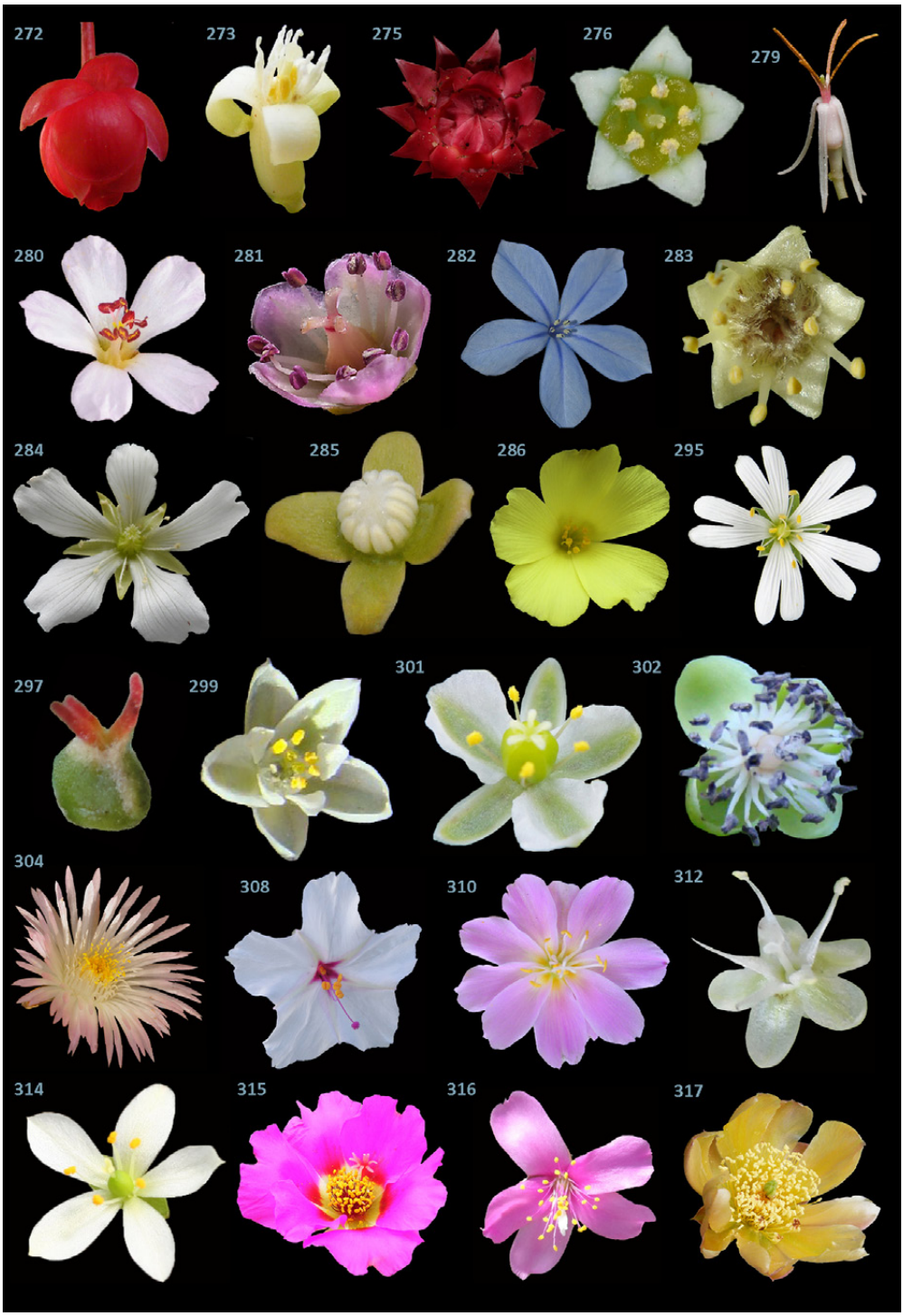

Figure 20: Floral images of Berberidopsidales (family 272), Santalales (273-279) and Caryophyllales (280-317).

ISSN 2398-6336 eISSN 2398-6344
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Asterids

17 orders : 99 families
(Basal asterids + lamiids + campanulids)

Stipules not common (about 15% of families)
Petals usually fused (about 75%)
Stamens often in a single whorl (about 80%)
Thin (tenuinucellate) nucellus (about 92%)
Single integument (about 88%)
Endosperm cellular (about 75%)
Iridoids often present
Gynoecial nectaries often present
Style solitary

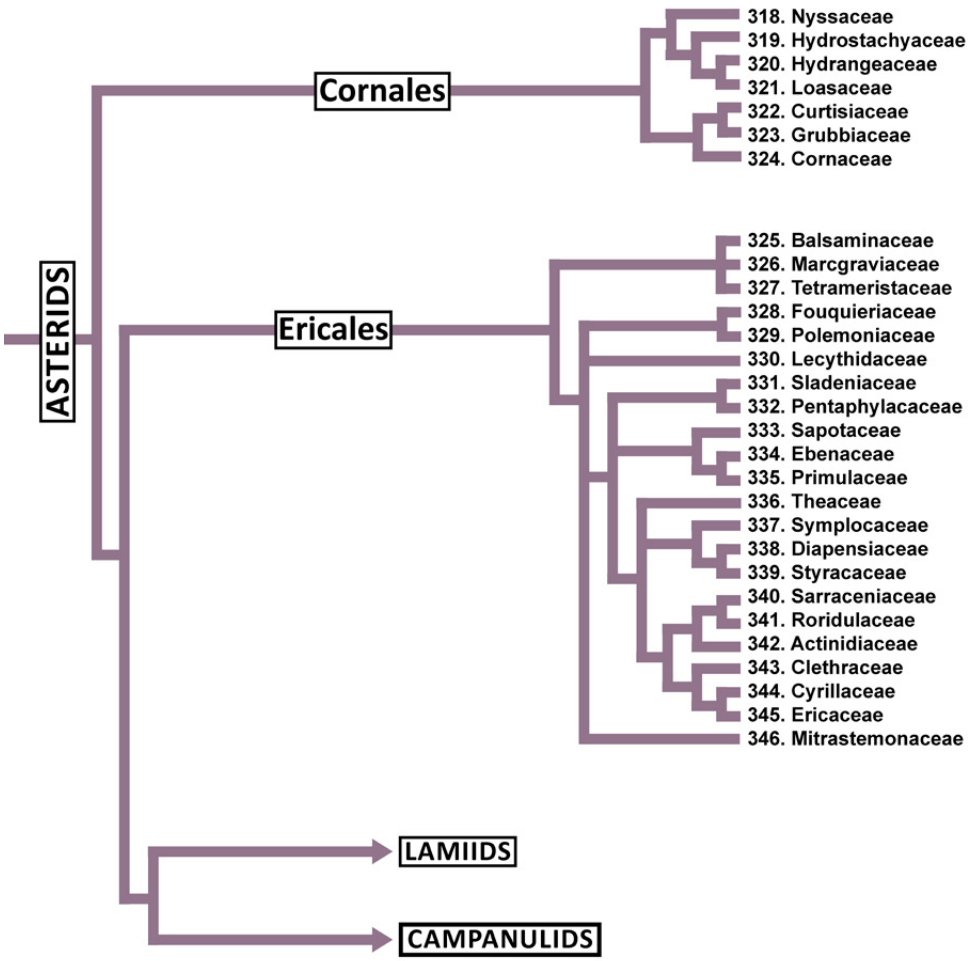

Figure 21: Diagnostic characters and relationships of asterids.

Published online 14 January 2018

ISSN 2398-6336 eISSN 2398-6344
ISBN 978-0-9929993-9-1

Figure 22: Floral images of Cornales (families 319-324) and Ericales (325-346).

ISSN 2398-6336 eISSN 2398-6344
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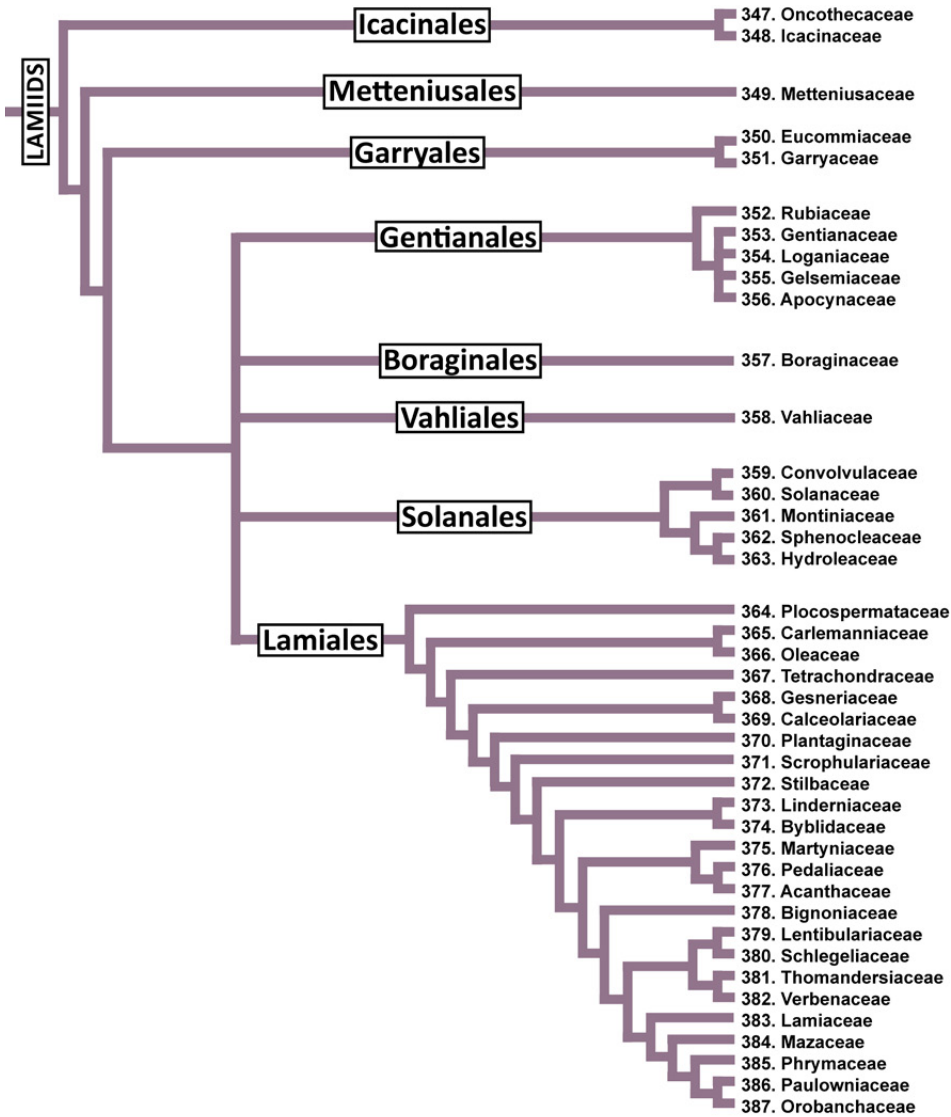

Figure 23: Relationships of lamiid asterids.

Figure 24: Floral images of Icacinales (family 348), Metteniusales (349), Garryales (351) and Gentianales (352).

Published online 14 January 2018

ISSN 2398-6336 eISSN 2398-6344
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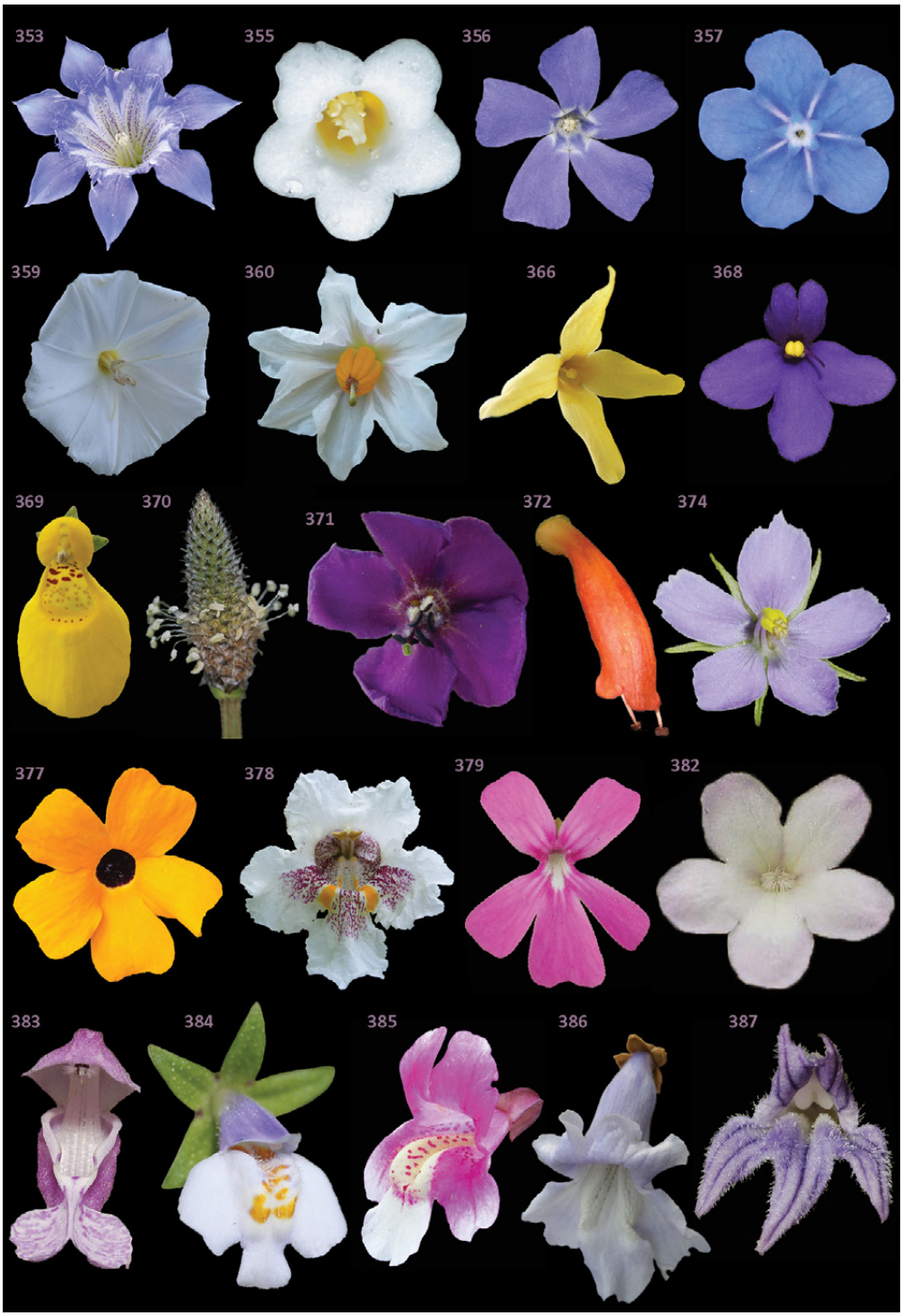

Figure 25: Floral images of Gentianales (families 353-356), Boraginales (357), Solanales (359-360) and Lamiales (366-387).

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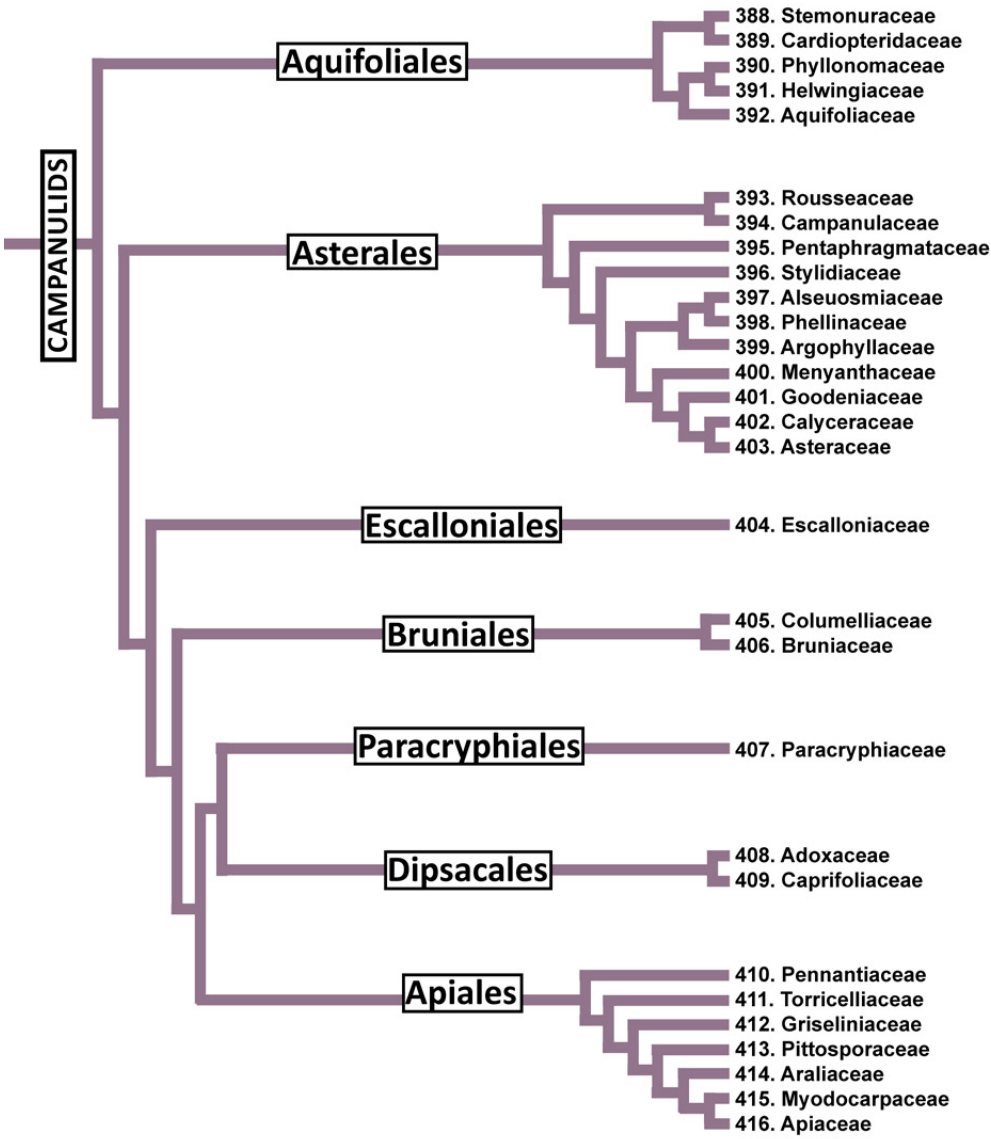

Figure 26: Relationships of campanulid asterids.

Published online 14 January 2018

ISSN 2398-6336 eISSN 2398-6344
ISBN 978-0-9929993-9-1

Figure 27: Floral images of Aquifoliales (families 388-392), Asterales (393-403), Escalloniales (404), Bruniales (405-406), Paracryphiales (407), Dipsacales (408-409) and Apiales (413-416).

ISSN 2398-6336 eISSN 2398-6344
ISBN 978-0-9929993-9-1

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ISBN 978-0-9929993-9-1

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