

Evidence on vegetative and inflorescence morphology of Chloranthaceae (Angiospermae) from the Early Cretaceous (middle-late Albian) of Spain

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Supplemental Appendix 1: characters used in phylogenetic analyses

EDH = character numbers of Eklund *et al.* (2004); when only one number is given, the character number is the same as in Eklund *et al.* (2004). We have simplified definitions of some characters that are not scored in any fossil taxa; see Eklund *et al.* (2004) for complete definitions. For mesofossils described since 2004, scoring usually follows that of equivalent characters in Doyle & Endress (2014, 2018), except when otherwise noted.

1. Growth form: (0) woody (tree, shrub, liana), (1) half-shrub, (2) herbaceous.
2. Aerial stems: (0) at least sometimes branched, (1) uniformly unbranched.
3. Stele: (0) eustele, (1) (pseudo)siphonostele.
4. Nodal anatomy: (0) multilacunar, (1) unilacunar one-trace, (2) unilacunar two-trace, (3) trilacunar.
5. Split-lateral traces: (0) absent, (1) present. Outgroups are scored only when nodes are of the unilacunar two-trace type.
6. Protoxylem lacunae: (0) absent, (1) present.
7. Cambium: (0) present, (1) absent.
8. Tracheary elements: (0) tracheids or elements with porose pit membranes, (1) vessel members with typical perforations.
9. Vessel grouping: (0) predominantly solitary, (1) mostly pairs or multiples.
10. Imperforate tracheary elements: (0) present, (1) absent.
11. Fiber pitting (lateral pitting of tracheids in vesselless taxa): (0) distinctly bordered, (1) minutely bordered or simple.
12. Rays: (0) narrow (generally not more than four cells wide), (1) wide.
13. Pericycle (including modified protophloem): with (0) separate fiber bundles, (1) more or less continuous ring of fibers or fibers alternating with non-U-shaped sclereids, (2) no sclerenchyma.
14. Laticifers in stem: (0) absent, (1) present.
15. Phyllotaxis: (0) spiral, (1) distichous (at least on branches), (2) opposite (decussate).
16. Leaf spacing: (0) regular, (1) apically subverticillate due to reduced internodes.
17. Number of leaves per main stem or branch: (0) more than four, (1) four.
18. First appendage(s) on vegetative branch: (0) paired lateral prophylls, (1) single prophyll (adaxial, oblique, or lateral).

In the outgroups to Chloranthaceae, we have scored four leaf characters that were treated as unknown by Eklund *et al.* (2004), namely length to width ratio (21), tooth form (23), mean number of secondary veins per side of leaf (26), and distance of looping or branching of secondary veins (29), observed in living plants at the UC Davis Botany Conservatory (*Amborella*, *Austrobaileya*) and herbarium specimens at Kew (K) (*Trimenia*), the UC Davis herbarium (DAV) (*Nuphar*, Cabombaceae, *Schisandra*, *Illicium*, Winteraceae, Asaroideae, Saururaceae), and the University of Zurich (Z) (tooth shape in *Schisandra*). In Winteraceae, ancestral conditions in variable characters were assessed assuming that the order of divergence of taxa was first *Takhtajania*, then *Tasmannia*, then *Drimys* (Karol *et al.* 2000; Thomas *et al.* 2014), with states in *Takhtajania* based on photos in Schatz (2000) and at <https://www.mobot.org/MOBOT/Madagasc/winterac.html>. This survey led us to make a few changes in scoring of other leaf characters in the outgroups, as noted below.

19. Leaf shape: (0) obovate to elliptical to oblong, (1) clearly ovate. Defined in terms of greatest width relative to the line from the petiole-blade attachment to the leaf apex in cordate and peltate leaves, not the whole leaf blade (Kvaček *et al.* 2016).

20. Leaf length (average of larger leaves on a branch): (0) less than 75 mm, (1) 75-140 mm, (2) more than 140 mm (ordered). Not scored in outgroups because length appears to be too labile within taxa.

21. Leaf length:width ratio: (0) more than 3, (1) 2-3, (2) less than 2 (ordered). In Chloranthaceae there appears to be a natural break in shape variation near L:W = 3, but this is not the case in Austrobaileales, for which we scored all four taxa as uncertain (0/1).

22. Chloranthoid teeth: (0) absent, (1) present (with glandular tip and a medial vein with one or two bracing conjunctals).

23. Tooth form: (0) low, asymmetrical, convex lower side, (1) prominent, acuminate on both sides or concave above, protruding gland, (2) symmetrical, low to protruding, convex to straight on both sides, low gland.

24. Densely sclerotic gland: (0) absent, (1) present (tooth type 3 of Todzia & Keating 1991).

25. Major venation: (0) pinnate with secondaries at more or less constant angle, (1) palmate (actinodromous or acrodromous) or crowded (pinnate with crowded basal secondaries, upward decreasing angle).

26. Mean number of secondary veins per side of leaf: (0) less than 10, (1) more than 10. Not scored (inapplicable) when venation is palmate.

27. Course of secondary veins: (0) curved, (1) straight to slightly recurved. Scoring of Winteraceae changed from (1) to (0) because secondaries are curved in *Takhtajania*, which is sister to the remaining genera, and the latter vary between curved and straight.

28. Secondary venation: (0) brochidodromous to semicraspedodromous, (1) festooned craspedodromous (secondaries branching, some branches looping, others entering teeth: Todzia & Keating 1991), (2) eucamptodromous or mixed with some brochidodromous loops.

29. Looping or branching of secondary veins: (0) well within the leaf margin (less than 0.8 of the distance from midrib to margin), (1) near margin (0.8 or more of the distance from midrib to margin).

30. Intramarginal vein: (0) absent, (1) present (submarginal vein of Todzia 1988).

31. Areas delimited by tertiary veins: (0) more or less isodiametric, (1) elongate parallel to secondaries. Scoring of *Trimenia* changed from (1) to (0/1) because some species have elongate tertiary areas but others have admedially ramified tertiary venation. Scoring of *Austrobaileya* changed from (1) to (0), since the alignment of tertiaries is more perpendicular to the midvein, rather than parallel to the secondaries. *Nuphar* changed from unknown to (0), since although tertiary areas are elongate near the leaf base they become isodiametric apically.

32. Leaf sheaths: (0) absent, (1) indistinct (seemingly fused to the stem, leaving a thickened ring rather than an open sheath when the leaf falls off); (2) distinct (forming a conspicuous open sheath around the stem).

33. Interpetiolar stipules (leaf sheath appendages): (0) absent, (1) present.

34. Two longitudinal, sometimes ciliate lines on leaf sheath running down from the bases of the stipular appendages: (0) absent, (1) present on at least some nodes.

35. Stomata (most common type on leaf): (0) paracytic, (1) anomocytic, (2) laterocytic, (3) stephanocytic (including tetracytic and cyclocytic). Following Kong (2001), Eklund *et al.* (2004) scored *Hedyosmum* and *Ascarina* as stephanocytic and (en)cyclocytic (EDH state 4), respectively. However, Carpenter (2005) showed that the two types differ only in degree and described both genera as stephanocytic, so following Kvaček *et al.* (2016) we have combined the two states.

36. Outer stomatal rims: (0) absent (level), (1) tall, raised.

37. Sculpture of abaxial cuticular membrane: (0) smooth, (1) striate, (2) insular.

38. Palisade parenchyma: (0) absent (mesophyll homogeneous), (1) present (mesophyll dorsiventral).

39. Astrosclereids in mesophyll: (0) absent, (1) present.

40. Oil cells in mesophyll: (0) absent, (1) present. Fossil taxa with oil cells in the carpels presumably had them in the leaves, but in the absence of direct evidence on leaf anatomy we treat this character as unknown in fossils, as in Doyle & Endress (2014, 2018).

41. Mucilage cells in mesophyll: (0) absent, (1) present.

42. Trichomes on leaf sheaths: (0) absent, (1) present. Scored only in Chloranthaceae because outgroups lack leaf sheaths. Characters 42 and 43 concern only conspicuous and more or less broad or scale-like trichomes.

43. Trichomes on stems, petioles, or veins: (0) absent, (1) present.

44. Papillae (on stems, petioles, veins, or leaf sheaths): (0) absent, (1) present.

45. Chromosome number: (0) $n = 8$, (1) $n = 13$, (2) $n = 15$ or 30. Scored only in Chloranthaceae.

46. Nucleotype: (0) diffuse or chromocenter type, (1) prochromosome type.

47. Sex distribution: (0) bisexual, (1) monoecious, (2) dioecious. Fossils with unisexual flowers are scored as (1/2), since there is no evidence on whether they are monoecious or dioecious.

Characters 48-54 apply to the bisexual inflorescences of *Chloranthus* and *Sarcandra* and the female inflorescences of *Ascarina* and *Hedyosmum*, except where otherwise indicated.

We have redefined the main inflorescence character (48) of Eklund *et al.* (2004) as three characters (48-50), following Endress & Doyle (2009) and Doyle & Endress (2014, 2018). Character 48 of Eklund *et al.* (2004) distinguished four states, (0) solitary flowers, (1) botryoids, (2) spikes or racemes, and (3) thyrses. This obscured the shared polytelic organization of spikes (*Sarcandra*, *Chloranthus*, most *Ascarina* species) and thyrses (*Hedyosmum* and other *Ascarina* species), which is a potential synapomorphy of Chloranthaceae. Our character 48 adds panicles and thyrsoids to botryoids in state (1) and combines racemes, spikes, and thyrses in state (2). Character 49 specifies whether inflorescence partial units are single flowers (as in botryoids and racemes) or cymes (as in thyrses and thyrsoids). Character 50 specifies whether a pedicel is present or absent to highly reduced (flower sessile or subsessile), which distinguishes spikes (with sessile flowers) from racemes.

48 (redefined). Inflorescence (0) solitary flower (or occasionally with 1–2 lateral flowers), (1) botryoid, panicle, or thyrsoid (monotelic), (2) raceme, spike, or thyrse (polytelic). Nymphaeales (Cabombaceae, *Nuphar*) rescored as having racemes (2) rather than solitary flowers (0), based on the morphological analyses of Chassat (1962) and Endress & Doyle (2009). Scoring of the *Asteropollis* plant as (2) is based on the male spikes, as in Eklund *et al.* (2004).

49 (new). Inflorescence partial units (0) single flowers, (1) cymes.

50 (new). Pedicel (0) present in some or all flowers, (1) absent or highly reduced. Scored as unknown in *Hedyosmum* species with pedunculate cymes, since it is uncertain whether elongation of the peduncle can be equated with elongation of the pedicel of a single flower (see character 56).

51 (EDH 49). Prophylls ('bracteoles') associated with flowers (in spikes) or cymes (in thyrses): (0) absent, (1) single (monochasial), (2) paired (dichasial). This character and characters 53 and 54 assume that cymes ('cymules') in *Hedyosmum* and some *Ascarina* species correspond to single flowers in other *Ascarina* species, *Chloranthus*, and *Sarcandra*.

52 (EDH 50). Grouping of spikes or thyrses: (0) all types (bisexual, male, and female) at least sometimes grouped into compound inflorescences, (1) female grouped, male simple, (2) female simple, male grouped, (3) all types simple. Scored as unknown in the outgroups because all except Saururaceae have inflorescence types other than spikes and thyrses, and Saururaceae and Chloranthaceae are too separated from each other for their spikes to be homologous. *Zlatkocarpus* is scored as (0/1) because female spikes are known to be grouped in *Z. pragensis* but male inflorescences are unknown in both species.

53 (EDH 51). Arrangement of flowers (in spikes) or cymes (in thyrses): (0) alternate or varying between opposite and alternate, (1) opposite (may show slight deviations at the base).

54 (EDH 52). Maximum number of flowers per spike or cymes per thyrses: (0) more than three, (1) three.

55 (EDH 53). Maximum number of flowers per cyme: (0) more than three, (1) three. Scored only in *Hedyosmum*.

56 (EDH 54). Base of cyme (in thyrses): (0) sessile, (1) sometimes or always with a distinct peduncle. Character 54 of Eklund *et al.* (2004) distinguished whether single flowers (in spikes) or cymes (in thyrses) were sessile or had a distinct pedicel or peduncle. Because it is not clear that the peduncle of a cyme is equivalent to the pedicel of a single flower, we have redefined the present character as referring to cymes and score it only in taxa with thyrses (*Hedyosmum*, *Ascarina lucida*, *A. swamyana*).

57 (EDH 55). Staminate spikes: (0) always on short peduncles (not longer than 1 cm), (1) at least sometimes on long peduncles (longer than 1 cm).

58 (EDH 56). Floral subtending bracts: (0) all flowers with a subtending bract, (1) male flowers without subtending bracts. *Zlatkocarpus* is scored as (0/1) because its female spikes have bracts but its male organs are unknown.

Characters 59-65 apply to bracts subtending bisexual and female flowers.

59 (EDH 57). Floral subtending bract fusion: (0) margins of bract free, not enclosing flowers, (1) margins of bract fused at least basally to enclose flower, bracts subtending adjacent flowers free or only partially fused to each other, (2) bracts subtending adjacent flowers almost completely fused to each other to enclose flowers ('bract matrix'). States (1) and (2) are restricted to *Hedyosmum* subgenus *Tafalla*. Eklund *et al.* (2004) scored the *Asteropollis* plant as (0), on the assumption that enclosing bracts would be retained around the dispersed fruits. However, because floral subtending bracts are not known in the *Asteropollis* plant (*Hedyflora*: Friis *et al.* 2019), we have rescored it as unknown for this and other bract characters (60-65).

60 (EDH 58). Shape of free floral subtending bracts: (0) short to long, acute or slightly acuminate, sometimes slightly three-lobed, (1) short, rounded to truncate, sometimes slightly two-lobed, (2) long, distinctly acuminate, with narrow apex more than a third the length of the bract, (3) uniformly three-lobed. Characters 60-64 are not scored in *Canrightia* and *Canrightiopsis* because their bracts are too reduced to be categorized, and the same is true for characters 61-63 in most other fossils. The large bract of *Alcainea* is not readily comparable to the bracts of any extant taxa, so we have scored it as unknown for characters 60-64.

61 (EDH 59). Margin of floral subtending bracts: (0) strictly entire, (1) irregularly serrate, (2) ciliate or papillate (some bracts may be entire).

62 (EDH 60). Wing-like membranous margin of floral subtending bract: (0) absent, (1) present.

63 (EDH 61). Base of floral subtending bract in fruit stage: (0) without decurrent ridges, (1) with wing-like decurrent ridges on dorsal side.

64 (EDH 62). Fruit subtending bracts: (0) not becoming fleshy, (1) becoming fleshy. State (1) is restricted to *Hedyosmum* subgenus *Tafalla*. Eklund *et al.* (2004) scored the *Asteropollis*

plant as (0), because fleshiness is always associated with enclosing bracts in *Hedyosmum*, but we have rescored this character as unknown, as discussed for character 59.

65 (EDH 63). Colour of fleshy fruit subtending bracts (in *Hedyosmum*): (0) white, (1) purple (dark).

66 (EDH 64). Perianth in bisexual or female flowers: (0) present, (1) absent.

67 (EDH 65). Perianth whorls (series when phyllotaxis is spiral): (0) more than two, (1) two, (2) one. Not scored in taxa with no perianth.

68 (EDH 66). Perianth phyllotaxis: (0) spiral, (1) whorled.

We eliminated the two floral merism characters of Eklund *et al.* (2004), for the perianth (EDH 67) and the androecium (EDH 112). Both included an ‘irregular’ state, which is redundant with the spiral state in the corresponding phyllotaxis characters (our characters 68, 112) and was therefore eliminated in the analysis of Endress & Doyle (2009, p. 25); the concept of merism is only applicable when parts are whorled. One of the two remaining states, for dimerous, tetramerous, and pentamerous, occurs only in Winteraceae, so the Eklund *et al.* (2004) characters would be phylogenetically uninformative with the present taxon sampling.

69 (EDH 68). Outer perianth whorl (series): (0) not clearly differentiated (or forming a continuum with inner parts), (1) sepaloid. Not scored for taxa with one perianth whorl.

70 (EDH 69, redefined). Tepals/perianth lobes: (0) free or fused only at base, (1) united more than basally. This character expresses variation within *Hedyosmum*; see Doyle & Endress (2014, p. 577) for the relation to their character 60, which included basally fused in state (1). Not scored in *Canrightia* and *Zlatkocarpus* because their tepals are too reduced to be categorized.

71 (EDH 70). Shape of tepals/perianth lobes: (0) acute or acuminate, (1) rounded or retuse. Tepals are too reduced to be scored in *Canrightia*, but they are acute in *Zlatkocarpus*.

72 (EDH 71). Number of carpels per flower: (0) more than one, (1) one.

73 (EDH 72 and 73, redefined). Adnation of outer floral parts to gynoecium: (0) free, (1) at least partially adnate (= inferior ovary). Eklund *et al.* (2004) treated adnation of tepals and stamens to the ovary as two separate characters (EDH 72, 73), but we have combined these as a single character because they both correspond to the inferior ovary state of one character in subsequent studies. Doyle & Endress (2014) scored *Sarcandra* and *Chloranthus* as unknown for this character (their character 48) because they were uncertain whether adnation of the androecium to the carpel could be compared with inferior ovary position in other taxa. However, as argued by Kvaček *et al.* (2016), its comparability is strengthened by the fact that both the tepals and stamens in *Canrightia* are attached to the ovary at the same level as the stamens in *Canrightiopsis* and *Chloranthus*. Eklund *et al.* (2004) scored *Ascarina lucida* as (0) for their character 73 because it has occasional units consisting of an abortive carpel and a stamen, which are not fused, but we score the present character as unknown because the nested position of *A. lucida* within *Ascarina* and the inconsistent presence of such units cast doubt on their homology with bisexual flowers in other Chloranthaceae.

74. Cross section of female flower: (0) trigonous, (1) round. This refers to the female flower of *Hedyosmum* and the *Asteropollis* plant (one carpel and three adnate tepals). Eklund *et al.*

(2004) treated other taxa as unknown, but the more recently described fossils *Canrightia* and *Zlatkocarpus* are comparable enough to be scored as round.

75. Ovary base: (0) short or with unridged stalk, (1) becoming stalk-like with longitudinal ridges.

76. Windows ('pores') in wall of female flower: (0) present in at least some specimens; (1) absent. Applicable only in taxa in which the perianth is adnate to the gynoecium (*Hedyosmum*, *Asteropollis* plant, *Canrightia*, *Zlatkocarpus*, Asaroideae).

77. Mature ovary wall: (0) coloured (purple, yellow, orange, red), (1) green, (2) white.

78. Ovule number: (0) one, (1) two or more. Confirmed in the *Asteropollis* plant (*Hedyflora*) by Friis *et al.* (2019).

79. Placentation: (0) linear (including one lateral or median), (1) laminar-diffuse (Nymphaeales).

80. Carpel form: (0) ascidiate up to stigma, (1) intermediate (both plicate and ascidiate zones present below the stigma) with ovule(s) in the ascidiate zone, (2) completely plicate, or intermediate with some or all ovule(s) in the plicate zone. Not scored in fossils because of lack of diagnostic developmental and anatomical data (see Doyle & Endress 2014).

81. Carpel fusion: (0) apocarpous, (1) parasyncarpous, (2) eusyncarpous (at least basally). Not scored in taxa with one carpel.

82. Carpel sealing: (0) by secretion, (1) partial postgenital fusion with continuous unfused canal containing secretion, (2) postgenital fusion to apex with partial canal containing secretion, (3) complete postgenital fusion without canal.

83. Pollen tube transmitting tissue: (0) not prominently differentiated, (1) at least one layer prominently differentiated.

84. Cells with calcium oxalate crystals in carpel wall: (0) absent, (1) present. The carpel wall in fossils is too collapsed to allow scoring.

85. Oil cells in carpel wall: (0) absent or internal, (1) intrusive.

86. Stigma shape: (0) more or less round and symmetrical or irregularly lobed, (1) with adaxial and abaxial lips, (2) with lateral lips or crests. Not scored in *Canrightia*, although it does have a circular raised area, because of questionable applicability to the syncarpous gynoecium. By contrast, the round area in *Canrightiopsis*, which is unicarpellate, can be scored as (0). The stigma in the *Asteropollis* plant is typically abraded or abscised (Friis *et al.* 2019).

87. Stigma base: (0) sessile, (1) on more or less elongate apical portion of carpel (= style).

88. Stigma surface: (0) papillate, (1) smooth.

89. Stigma duration: (0) persistent, (1) caducous.

90. Extragynoecial compitum: (0) absent, (1) present. Not scored in taxa with one carpel and fossils.

91. Fruit wall (0) fleshy, (1) fleshy with hard endocarp (= drupe), (2) dry, (3) hard with aril-like outgrowths.

92. Fruit dehiscence: (0) indehiscent, (1) dehiscent. Names of these states were inadvertently reversed in Eklund *et al.* (2004), but their scoring correctly followed the present definition.

93. Staminal scar on fruit: (0) without supporting structure, (1) with supporting structure. Friis *et al.* (2015) described some specimens of *Canrightiopsis* as having a ‘rim’ on the androecium side, but because this is not clearly comparable we score the character as unknown.

94. Ovule curvature: (0) anatropous, (1) orthotropous (including hemitropous). Scoring of the *Asteropollis* plant for this and other ovule and seed characters is based on Friis *et al.* (2019).

95. Ovule direction: (0) pendent, (1) horizontal, (2) ascendent.

96. Outer integument thickness (at middle of integument length): (0) two cells, (1) two and three to four, (2) four and five, or more.

97. Inner integument thickness: (0) two cells, (1) two and three, or three, (2) three and more.

98. Micropyle formed of: (0) inner integument, (1) both integuments.

99. Inner integument lobation: (0) not lobed, (1) at least sometimes lobed.

100. Outer integument lobation: (0) unlobed, (1) at least sometimes lobed.

101. Seed coat surface: (0) smooth, (1) minutely papillate, (2) warty-papillate.

102. Testa: (0) slightly or non-multiplicative, (1) multiplicative.

103. Exotesta: (0) unspecialized, (1) palisade or shorter sclerotic cells.

104. Mesotesta: (0) unspecialized, (1) sclerotic, (2) sarcotesta. Not scored in taxa with only two cell layers in the outer integument.

105. Endotesta: (0) unspecialized, (1) single lignified layer (cells with thin walls but fibrous endoreticulum).

106. Tegmen: (0) unspecialized, (1) both exo- and endotegmen consisting of thick-walled cells, (2) exotegmen fibrous to sclerotic. Scored as (0) in *Canrightia*; Friis and Pedersen (2011) described the seed as endotegmic, but the inner layer is an endothelium of thin-walled cells that is crushed in the mature seed, not a structural layer.

107. Operculum: (0) absent, (1) present.

108. Perisperm: (0) absent, (1) present.

109. Germination: (0) epigeal, (1) hypogeal.

110. Stamen number per flower: (0) at least sometimes more than one, (1) one. Whereas Eklund *et al.* (2004) scored the three-lobed androecium of *Chloranthus* and *Chloranthistemon* as unknown, to allow for the hypothesis that it originated by dissection of a single stamen, we have rescored it as consisting of more than one stamen. This is based on the fact that *Canrightiopsis* has three free stamens adnate to the dorsal side of the carpel and appears to be sister to *Sarcandra* and *Chloranthus*, which suggests that the *Chloranthus* androecium originated by fusion of three stamens (Friis *et al.* 2015; Doyle & Endress 2018).

111 (new). Androecium symmetry: (0) stamens arranged more or less evenly around the flower, (1) three stamens or stamen lobes situated on one side of the flower, forming a monosymmetric unit. State (1) expresses the distinctive morphology of the androecium in *Chloranthus*, *Chloranthistemon*, and *Canrightiopsis*. Taxa with one stamen are scored as unknown, since the one stamen could be derived from an androecium with the stamens in either arrangement.

112 (EDH 111). Androecium phyllotaxis: (0) spiral, (1) whorled. Because stamen phyllotaxis is unclear even in *Ascarina* species with more than one stamen, all living Chloranthaceae are treated as unknown.

See note after character 68 on elimination of the Eklund *et al.* (2004) character for merism of the androecium (EDH 112).

113. Stamen base: (0) short (less than 2/3 length of anther), (1) long (more than 2/3 length of anther) and wide (more than 1/2 width of anther), (2) long and narrow (less than 1/2 width of anther: typical filament).

114. Stamen lobation and number of thecae: (0) normal tetrasporangiate stamens, with two thecae, (1) three-lobed androecium, two thecae on each lobe, (2) three-lobed androecium, two thecae on median lobe, one on each lateral lobe, (3) three-lobed androecium, no thecae on median lobe, one on each lateral lobe. Scoring of the *Asteropollis* plant as (0) is based on Friis *et al.* (2019, fig. 3A).

115 (redefined). Stamen fusion: (0) basally free or joined only at the very base, (1) joined part way (up to *c.* 2/3 of length), (2) joined almost completely. Eklund *et al.* (2004) defined this character in terms of degrees of androecial lobation and scored it only in *Chloranthus* and *Chloranthistemon* because of uncertainty on whether their lobed androecium represents one or three stamens. With our reinterpretation of the lobed androecium as derived from three stamens (see character 110), we have redefined the present character in terms of degrees of stamen fusion and have scored it as (0) in the outgroups and those *Ascarina* species with more than one stamen. Some *Schisandra* species have fused stamens, but not others; we have rescored *Schisandra* as unfused (0) based on phylogenetic evidence that free stamens are ancestral in the genus (Dong *et al.* 2012).

116. Connective apex: (0) truncate or rounded, (1) short pointed extension (apiculus), (2) large, wide apical lobe (rounded to acute), (3) long narrow lobes. Eklund *et al.* (2004) scored this character as unknown in the *Asteropollis* plant, but based on figures in Friis *et al.* (2011) Doyle & Endress (2014) scored the equivalent character as truncate or rounded (state 1 of their character 72), which we follow here (our state 0).

117. Stamen shape: (0) elliptical, tongue-shaped, apex same width or narrower than rest of stamen, (1) obovate-obtriangular, apex wider than rest of stamen (often overhanging the pollen sacs). Scoring of the *Asteropollis* plant as (0) is based on Friis *et al.* (2019, fig. 3A).

118. Colour of stamens: (0) white (cream), (1) yellow-green, (2) red.

119. Connective hypodermis: (0) unspecialized, (1) endothecial or sclerenchymatous.

120. Outer surface of pollen sacs: (0) smooth, (1) slightly papillose, (2) distinctly papillose.

121. Orientation of anther dehiscence: (0) distinctly introrse, (1) latrorse to slightly introrse, (2) extrorse.

122. Anther dehiscence: (0) longitudinal slit, (1) lateral valves (H-valvate). Unclear in the single attached stamen of *Canrightia* (Friis & Pedersen 2011).

123. Pollen diameter: (0) less than 20 μm , (1) 20-50 μm , (2) more than 50 μm . Most fossils measuring less than 20 μm are scored as (0/1), except when much smaller than 20 μm (e.g., *Canrightiopsis*), since size may be biased by shrinkage during preservation.

124. Pollen shape: (0) boat-shaped, (1) globose.

125. Aperture type: (0) monosulcate or occasionally trichotomosulcate (including monoulcerate, disulcate, and two perpendicular furrows), (1) syntriolpate, with or without three alternating colpi, (2) spiraperturate, (3) several-branched sulcus, (4) polycolpate, (5) polyforate.

126. Tectum: (0) continuous or microperforate, (1) foveolate or reticulate, including rugulo-reticulate.

127. Size of lumina relative to width of muri: (0) small (foveolate: all lumina smaller than width of the muri), (1) medium, (2) large (open reticulate: many lumina twice as large as width of the muri), (3) graded from finer at the equator to coarser at the poles. Not scored in taxa with a continuous or microperforate tectum. In taxa with two distinct sizes of lumina (128), this character refers to size of the larger lumina.

128. Differentiation of lumina: (0) one size (homobrochate), (1) two distinct sizes, with very small lumina at the junctions of the muri (heterobrochate). Not scored in taxa in which all lumina are small.

129. Supratectal spines/verrucae (smaller than the width of tectal muri when reticulate): (0) absent, (1) present.

130. Infratectum: (0) granular, (1) intermediate, (2) columellar. Scoring of *Amborella* and Cabombaceae changed from (1) to (2) and that of *Nuphar* from (0) to (1), following Doyle (2005) and Doyle & Endress (2014). With these changes the character becomes phylogenetically uninformative, but we have retained it for comparability with other data sets.

131. Nexine: (0) thin (less than 1/3 of exine thickness), (1) thick (1/3 or more of exine thickness).

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