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Fossil evidence of core monocots in the Early Cretaceous

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Fossil Analysis

Fossil analysis

The fossils were studied using a Leica Wild M8 light microscope equipped with a DFC420 digital camera. Cellular details of the epidermis of the leaves, such as anatomy and arrangement of stomata, or arrangement of non-modified epidermal cells, were partly visible under the light microscope. Details of the anatomy were observed with a scanning electron microscope (SEM). For SEM studies, pieces of leaves were removed from the specimens, directly mounted on stubs and twice coated with Au/Pd for four minutes with a Polaron SC7640 sputter coater. SEM images were taken on a Zeiss EVO 50 SEM and processed with GIMP (v.2.6.6, GNU Image Manipulation Programme, free software, <http://www.gimp.org>).

Tomographic reconstruction

The μ CT system used at Helmholtz-Zentrum Berlin consists in a micro-focus 150 kV Hamamatsu X-ray source with a tungsten target and a flat panel detector C7942 (120x120 mm², 2240x2368 pixel², pixel size 50 μ m). Figure 1 shows a photograph of the system used. A 100 kV filament voltage and a current of 100 μ A with an exposure time of 1.3 seconds were used in this scan since these parameters provided the best results. Image noise was reduced by using a 5-fold integration. The source-detector distance was 450 mm while the source-object distance was 130 mm in order to get the optimal magnification providing a spatial resolution of 14 μ m. The number of acquired projections was 1000 images which yields a total scanning time of 40 minutes. In the X-ray cabinet the sample was rotated in a precision rotation stage from Huber, Germany. A commercial software (Octopus V8.6) was used to implement the back-projection algorithm with convolution and correction for cone beam, so the internal structure of the sample was reconstructed from the 2D angular projections.

The resulting tomographical dataset was imported into SPIERSEdit (Sutton et al., 2012), where separation of the fossil from the surrounding matrix was achieved through a combination of thresholding and masking. Individual 'masks' were assigned to distinct anatomical structures that were rendered as separate isosurfaces. This process allowed the production of accurate false-color models that emphasized the spatial relationships among the anatomical structures, which could then be virtually manipulated within three-dimensional-space using SPIERSView (Sutton et al., 2012).

First cladistic analysis based on Endress and Doyle (2009)

The first phylogenetic analysis was performed by adding the fossil states to the existing phylogenetic dataset from Doyle & Endress (2010).

The most parsimonious configuration were evaluated using TNT (Goloboff et al., 2003). Alternative positions of the fossil were then investigated by linking the fossil to all possible branches of the backbone tree using Mesquite (Maddison and Maddison, 2011) and recalculating the number of required parsimony changes (steps) in each alternative tree. All characters were unordered and heuristic searches were made using 1000 random addition replicates with tree-bisection-reconnection (TBR) branch swapping with MULTREES on.

List of characters coded in the phylogenetic analyses. Character states coded for the fossil are in bold.

- 01. Habit (0) tree or shrub, **(1) rhizomatous, scandent, or acaulescent**.
- 09. Phyllotaxis **(0) alternate (spiral or distichous)**, (1) opposite or whorled.
- 10. Distichous phyllotaxis **(0) absent**, (1) on some or all branches.
- 12. Monocots + Leaf base (0) nonsheathing, **(1) sheathing**.
- 13. Stipules **(0) absent**, (1) adaxial/axillary, (2) interpetiolar, (3) paired cap.

15. Leaf blade (0) bifacial, **(1) unifacial**.
16. Leaf shape (0) obovate to elliptical to oblong, (1) ovate, **(2) linear**.
17. 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), **(2) parallel (lateral veins departing at low angles from the midrib and converging and fusing apically)**.
18. Fine venation **(0) reticulate**, (1) open dichotomous in some or all leaves.
19. Base of blade **(0) not peltate**, (1) peltate in some or all leaves.
20. Leaf dissection **(0) simple**, (1) some or all leaves lobed or compound.
22. Inflorescence (0) solitary flower (or occasionally with 1 – 2 lateral flowers), **(1) botryoid, panicle, or thyrse (monotelic), (2) raceme, spike, or thyrse (polytelic)**.
24. Pedicel (0) present in some or all flowers, **(1) absent or highly reduced (flower sessile or subsessile)**.
27. Floral base **(0) hypanthium absent, superior ovary**, (1) hypanthium present, superior ovary, (2) partially or completely inferior ovary.
28. Floral receptacle (female portion) **(0) short**, (1) elongate.
30. Floral apex **(0) used up after production of carpels**, (1) protruding in mature flower.
39. Calyptra derived from last one or two bracteate organs below the flower **(0) absent**, (1) present.
74. Carpel number **(0) more than one**, (1) one.
84. Carpel fusion (0) apocarpous (including pseudosyncarpous), **(1) parasyncarpous, (2) eusyncarpous (at least basally)**.

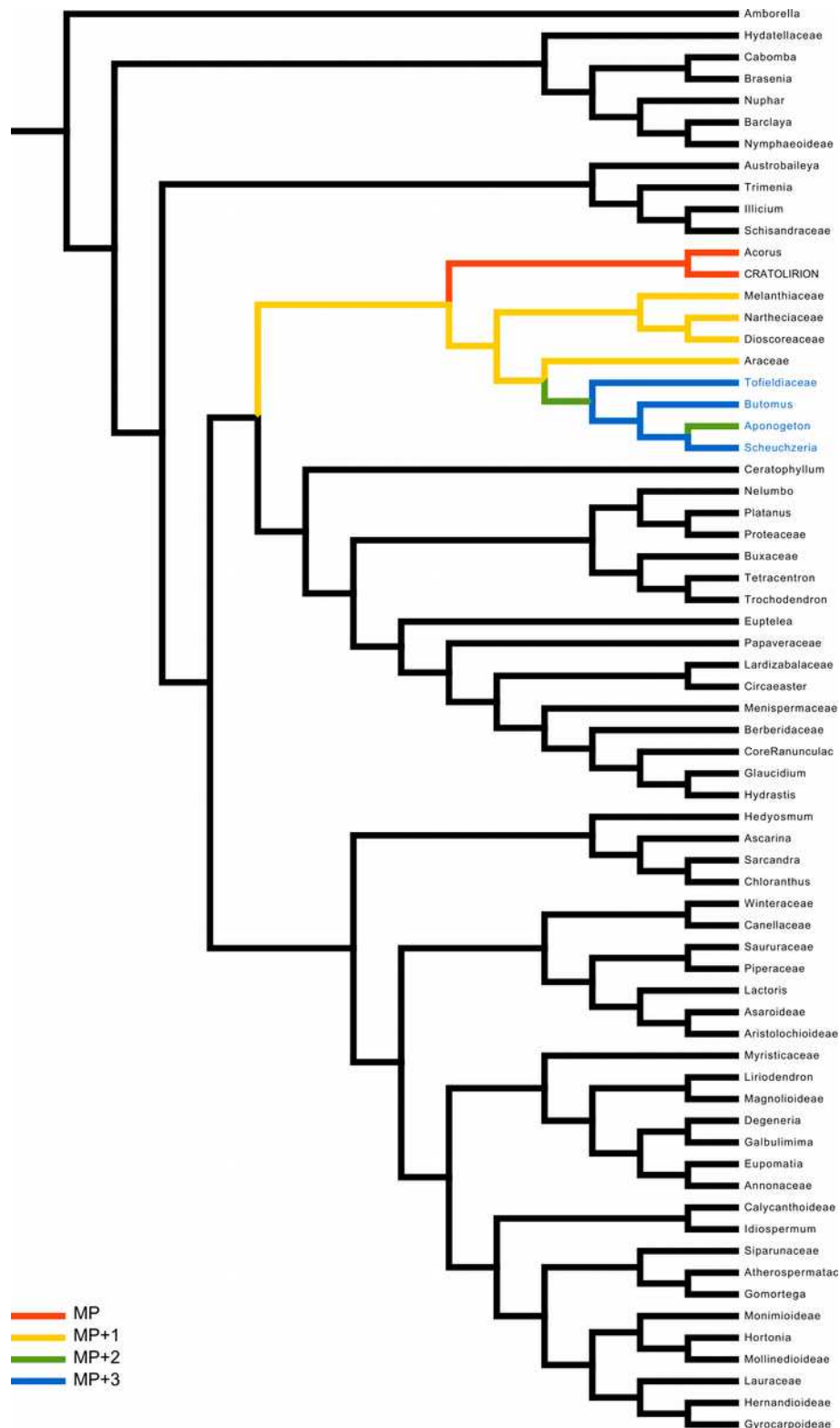


Figure 1: Single most parsimonious position obtained after the addition of *Cratolirion bogneriana* to the Endress and Doyle (2009) matrix. Color scale indicate all most parsimonious (MP), one step less parsimonious (MP + 1), two steps less parsimonious (MP + 2) positions and three steps less parsimonious (MP + 3) positions.

New Matrix

The new matrix was built based on Stevenson and Loconte (1995) completed by Rudall et al. (1999), Rudall (2002), Michelangeli et al. (2003) and Petersen et al. (2016) resulting in a supermatrix with 175 taxa and 290 characters and 47% of completeness (23887/50750).

In some cases, the characters had to be rescored. The most common case was a simple inversion but in other cases, a character state was more broadly defined in a matrix than in the other. In this latter case, the most precise coding was used, resulting in polymorphic states for the less precise matrix. In case of conflict in character coding between matrix, the most recent matrix was preferred. When the S&L matrix presented only a family level resolution, the character states were applied to each species.

Recent taxa

- 001. Acorus (P15)
- 002. Tofieldia (P15)
- 003. Pleea (P15)
- 004. Arisaema (P15)
- 005. Calla (P15)
- 006. Gymnostachys (P15)
- 007. Orontium (P15)
- 008. Symplocarpus (P15)
- 009. Hydrocleys (P15)
- 010. Limnocharis (P15)
- 011. Luronium (P15)
- 012. Alisma (P15)
- 013. Baldellia (P15)
- 014. Caldesia (P15)
- 015. Ranalisma (P15)
- 016. Helanthium (P15)
- 017. Sagittaria (P15)
- 018. Echinodorus (P15)
- 019. Butomus (P15)
- 020. Stratiotes (P15)
- 021. Blyxa (P15)
- 022. Ottelia (P15)
- 023. Lagarosiphon (P15)
- 024. Hydrocharis (P15)
- 025. Limnobium (P15)
- 026. Egeria (P15)
- 027. Elodea (P15)
- 028. Najas (P15)
- 029. Hydrilla (P15)
- 030. Nechamandra (P15)
- 031. Vallisneria (P15)
- 032. Halophila (P15)
- 033. Enhalus (P15)
- 034. Thalassia (P15)
- 035. Aponogeton (P15)
- 036. Scheuchzeria (P15)
- 037. Cycnogeton (P15)
- 038. Lilaea (P15)
- 039. Triglochin (P15)
- 040. Maundia (P15)
- 041. Zannichellia (P15)
- 042. Potamogeton (P15)

043. Phyllospadix (P15)
044. Zostera (P15)
045. Heterozostera (P15)
046. Ruppia (P15)
047. Posidonia (P15)
048. Halodule (P15)
049. Syringodium (P15)
050. Amphibolis (P15)
051. Cymodocea (P15)
052. Petrosavia (P15)
053. Talbotia (P15)
054. Freycinetia (P15)
055. Carludovica (P15)
056. Narthecium (P15)
057. Tacca (P15)
058. Dioscorea (P15)
059. Tamus (P15)
060. Alstroemeria (P15)
061. Trillium (P15)
062. Chamaelirium (P15)
063. Veratrum (P15)
064. Philesia (P15)
065. Smilax (P15)
066. Calochortus (P15)
067. Lilium (P15)
068. Clintonia (P15)
069. Apostasia (R02)
070. Neuwiedia (R02)
071. Vanilla (R02)
072. Cypripedium (R02)
073. Epipactis (R02)
074. Orchis (R02)
075. Borya (R02)
076. Blandfordia (R02)
077. Astelia (R02)
078. Lanaria (R02)
079. Collospermum (R02)
080. Milligania (R02)
081. Curculigo (R02)
082. Empodium (R02)
083. Hypoxis (R02)
084. Molineria (R02)
085. Pauridia (R02)
086. Rhodohypoxis (R02)
087. Spiloxene (R02)
088. Ixiolirion (R02)
089. Conanthera (R02)
090. Cyanastrum (R02)
091. Cyanella (R02)
092. Kabuyea (R02)
093. Odontostomum (R02)
094. Tecophilaea (R02)

- 095. Walleria (R02)
- 096. Zephyra (R02)
- 097. Doryanthes (R02)
- 098. Isophysis (R02)
- 099. Diplarrhena (R02)
- 100. Iris (R02)
- 101. Tigridia (R02)
- 102. Patersonia (R02)
- 103. Geosiris (R02)
- 104. Gladiolus (R02)
- 105. Xeronema (R02)
- 106. Aloe (R02)
- 107. Asphodeline (R02)
- 108. Asphodelus (R02)
- 109. Bulbine (R02)
- 110. Eremurus (R02)
- 111. Kniphofia (R02)
- 112. Trachyandra (R02)
- 113. Xanthorrhoea (R02)
- 114. Caesia (R02)
- 115. Dianella (R02)
- 116. Hemerocallis (R02)
- 117. Phormium (R02)
- 118. Simethis (R02)
- 119. Anthericum (R02)
- 120. Paradisea (R02)
- 121. Dasypogon (M03)
- 122. Calectasia (M03; R99)
- 123. Kingia (M03)
- 124. Baxteria (M03)
- 125. Nypa (R99)
- 126. Trithrinax (R99)
- 127. Plectocomia (R99)
- 128. Sparganium (M03; R99)
- 129. Typha (M03; R99)
- 130. Tillandsia (M03; R99)
- 131. Catopsis (M03; R99)
- 132. Puya (M03; R99)
- 133. Rapatea (M03; R99)
- 134. Schoenocephalum (M03; R99)
- 135. Stegolepis (M03; R99)
- 136. Eriocaulon (M03; R99)
- 137. Tonina (M03; R99)
- 138. Xyris (M03; R99)
- 139. Abolboda (M03; R99)
- 140. Orectanthe (M03; R99)
- 141. Mayaca (M03; R99)
- 142. Thurmia (M03; R99)
- 143. Pronium (M03; R99)
- 144. Luzula (M03; R99)
- 145. Juncus (M03; R99)
- 146. Cladium (M03; R99)

147. *Carex* (M03; R99)
148. *Anarthria* (M03; R99)
149. *Aphelia* (M03; R99)
150. *Baloskion* (M03; R99)
151. *Leptocarpus* (M03; R99)
152. *Lepyrodia* (M03; R99)
153. *Elegia* (M03; R99)
154. *Thamnochortus* (M03; R99)
155. *Flagellaria* (M03; R99)
156. *Joinvillea* (M03; R99)
157. *Ecdeiocolea* (M03; R99)
158. *Anomochloa* (M03; R99)
159. *Streptochaeta* (M03; R99)
160. *Pharus* (M03; R99)
161. *Bambusa* (M03; R99)
162. *Oryza* (M03; R99)
163. *Commelinaceae* (R99)
164. *Hanguana* (R99)
165. *Philydraceae* (R99)
166. *Haemodoraceae* (R99)
167. *Pontederiaceae* (R99)
168. *Musaceae* (R99)
169. *Heliconia* (R99)
170. *Strelitziaceae* (R99)
171. *Lowia* (R99)
172. *Canna* (R99)
173. *Marantaceae* (R99)
174. *Costaceae* (R99)
175. *Zingiberaceae* (R99)

Characters and source of data

The following abbreviations refer to the character numbers in the respective publications.

S&L: Stevenson and Loconte, 1995

R99: Rudall et al., 1999

R02: Rudall, 2002

M03: Michelangeli et al., 2003

P15: Petersen et al., 2015

001. MYCOTROPHY: absent (0), present (1) (S&L-001; R99-000; P15-001)
002. ROOT HAIR ORIGIN: any cell (0), specialised cells (1) (S&L-002; R99-003; M03-000; P15-003)
003. VELAMEN: absent (0), present (1) (S&L-003; R99-001; R02-005; P15-004)
004. LATERAL ROOT ORIGIN: opposite xylem (0), opposite phloem (1), both (2) (S&L-004; R99-004; M03-001; P15-005)
005. ROOT VESSELS: absent (0), present (1) (S&L-004 modified; R99-005 modified; P15-006)
006. UNDERGROUND STEM: rhizome (0), corm (1), bulb (2), tuber (3) (S&L-007; R99-010; R02-001 modified; P15-014)
007. STEM VESSELS: absent (0), present (1) (S&L-008 modified; R99-011 modified; M03-004 modified; P15-015)

008. STELE: eustely (0), atactostely (1), reduced (2) (S&L-009; R99-012; M03-005 modified; P15-017)
009. SIEVE-TUBE PLASTIDS: S (0), P11c (1), P11cs (2), P11c' (3) (S&L-010; R99-013)
010. LATICIFERS: absent (0), present (1) (S&L-011; R99-014; P15-018)
011. VEGETATIVE OXALATE RAPPHIDES: absent (0), present (1) (S&L-012; R99-015; R02-018; M03-007; P15-021)
012. SILICA BODIES: absent (0), present (1) (S&L-013; R99-016; R02-020; P15-026)
013. LEAF BLADE: simple (0), ensiform (1), scale (2), divided (3), terete (4), reduced (5) (S&L-014; R99-022; M03-013; P15-032)
014. LEAF VESSELS: absent (0), present (1) (S&L-015 modified; R99-023 modified; M03-014 modified; P15-034)
015. PTYXIS: adplicate (0), supervolute (1), conduplicate (2), plicate (3), involute (4), explicative (5) (S&L-016; R99-024; M03-015; P15-035)
016. PHYLOTAXIS: spiral (0), ranked (1) (S&L-017; R99-025; M03-016; P15-036)
017. PETIOLE: absent (0), Dioscorea (1), Alisma (2), Bambusa (3) (S&L-018; R99-026; M03-017; P15-037)
018. STIPULES: absent (0), present (1) (S&L-019; R99-027; P15-039)
019. LIGULE: absent (0), present (1) (S&L-020; R99-028; M03-018; P15-040)
020. INTRAVAGINAL SQUAMULES: absent (0), present (1) (S&L-021; R99-029; P15-047)
021. PRIMARY VENATION: palmate (0), pinnate (1), parallel (2), dichotomous (3) (S&L-022; R99-030; P15-048)
022. RETICULATE VENATION: absent (0), present (1) (S&L-023; R99-031; P15-049)
023. PUBESCENCE: absent (0), present (1) (S&L-024; R99-032; M03-019; P15-050)
024. GLANDULAR HAIRS: absent (0), present (1) (S&L-025; R99-033; M03-020; P15-051)
025. LEAF AXIL HAIRS: absent (0), present (1) (S&L-026; R99-034; M03-021; P15-052)
026. LEAF EPIDERMIS: undifferentiated (0), short/long cells (1) (S&L-027; R99-038; M03-024; P15-057)
027. STOMATA: absent (0), para or tetracytic (1), anomocytic (2) (S&L-029 modified; R99-039 modified; M03-025; P15-058)
028. LEAF AIR CANALS: absent (0), random (1), one arc (2), two or more arcs (3) (S&L-030; R99-036; M03-022; P15-054)
029. INFLORESCENCE: solitary flower (0), cyme (1), panicle (2), raceme (3), spike (4), spadix (5), head (6) (S&L-031; R99-047)
030. FLORAL EXPRESSION: monoclinal (0), diclinous (1) (S&L-032; R99-048; R02-024; M03-028; P15-090)
031. TEPALS SPOTTED: absent (0), present (1) (S&L-034; R99-050; P15-097)
032. PERIANTH CONNATION: absent (0), present (1) (S&L-035; R99-053)
033. PERIANTH CURVATURE: absent (0), present (1) (S&L-036; R99-056; P15-109)
034. ZYGOMORPHY: absent (0), present (1) (S&L-037; R99-057)
035. PERIGONAL NECTARIES: absent (0), present (1) (S&L-038; R99-058; R02-026 modified; P15-110)
036. STAMINODIA: absent (0), present (1) (S&L-040; R99-061)
037. CONNATE STAMEN FILAMENTS: absent (0), present (1) (S&L-041; R99-062)
038. CONNECTIVE PROTUSION: absent (0), present (1) (S&L-042; R99-063; M03-037; P15-123)
039. ANTHER ATTACHMENT: basifixed (0), dorsifixed (1), ventrifixed (2), peltate (3) (S&L-043; R99-064; M03-038; P15-124)
040. ANTHER DEHISCENCE ORIENTATION: introse (0), extrose (1), latrose (2) (S&L-044; R99-065; R02-042 modified; M03-039; P15-125)
041. ANTHER DEHISCENCE: longitudinal (0), poricidal (1), valvar (2) (S&L-045; R99-066; M03-040; P15-126)
042. SPORANGIA PER ANTHER: tetrasporangiate (0), bisporangiate (1) (S&L-046; R99-067)

043. ANTHER WALL FORMATION: dicotyledonous (0), monocotyledonous (1), basic type (2), reduced type (3) (S&L-047; R99-068; P15-129)
044. ENDOTHECIAL WALL THICKENINGS: spiral (0), girdle like (1), stellate (2), absent (3) (S&L-048; R99-069; M03-043; P15-130)
045. TAPETUM TYPE: glandular/secretory (0), plasmodial/amoeboid (1) (S&L-049; R99-070; R02-044; M03-044; P15-132)
046. MICROSPOROGENESIS: successive (0), simultaneous (1), modified simultaneous (2) (S&L-050; R99-071; R02-050; M03-045; P15-133)
047. POLLEN UNITS: monads (0), tetrads (1), dyads (2), moniliform chains (3) (S&L-051; R99-072; M03-046; P15-134)
048. POLLEN APERTURE MARGIN: nonannulate (0), annulate (1) (S&L-054; R99-078; M03-050; P15-141)
049. POLLEN WALL ULTRASTRUCTURE: columellate (0), granular (1), aveolar (2), atectate (3) (S&L-056; R99-079; M03-051; P15-142)
050. ENDEXINE: absent (0), present (1) (S&L-057; R99-081; M03-053; P15-145)
051. POLLEN NUCLEI: two (0), three (1) (S&L-058; R99-082; M03-054; P15-146)
052. SEPTAL NECTARIES: absent (0), internal (1), external (2) (S&L-059; R99-094; R02-056 modified; M03-062; P15-161)
053. CARPEL CONNATION: apocarpous (0), syncarpous (1) (S&L-060; R99-088; P15-155)
054. EMBRYOSTEGA: absent (0), outer integument (1), inner integument (2), both (3) (S&L-061; R99-096; M03-064; P15-171)
055. GYNOECIUM POSITION: superior (0), inferior (1) (S&L-062; R99-083; P15-147)
056. STIGMATIC SURFACE: dry (0), wet (1) (S&L-064; R99-084; M03-055; P15-150)
057. OVULE TYPE: anatropous (0), campylotropous-amphitropous (1), orthotropous (2) (S&L-066; R99-100; M03-066; P15-174)
058. NUCELLUS: crassinucellate (0), tenuinucellate (1), pseudo-crassinucellar (2) (S&L-067; R99-095; M03-063; P15-162)
059. NUCELLAR CAP: absent (0), present (1) (S&L-068; R99-104; M03-069; P15-178)
060. STIGMA: symmetric (0), asymmetric (1) (S&L-069; R99-085; P15-151)
061. ENDOSPERM FORMATION: cellular (0), nuclear (1), helobial (2) (S&L-070; R99-106; M03-070; P15-182)
062. EMBRYOGENY: onagrad (0), caryophyllad (1), solanad (2), asterad (3), chenopodiad (4) (S&L-071; R99-107; M03-071; P15-180)
063. FRUIT TYPE: follicle (0), achene (1), drupe (2), berry (3), utricle (4), capsule (5), schizocarp (6), nutlet (7), samara (8) (S&L-072 modified; R99-114 modified; R02-058 modified; M03-075 modified; P15-188)
064. ARILS: absent (0), present (1) (S&L-073; R99-097; R02-059; P15-199)
065. PHYTOMELAN SEEDS: absent (0), present (1) (S&L-074; R99-115; R02-060; P15-197)
066. MICROSPERMY: absent (0), present (1), minute (2) (S&L-075; R99-116; P15-198)
067. STARCHY ENDOSPERM: none or little (0), abundant (1) (S&L-077; R99-109; M03-072; P15-184)
068. EMBRYO TYPE: linear (0), lateral (1), capitate (2), broad (3), rudimentary (4), minute (5) (S&L-078; R99-117; M03-076; P15-209)
069. MACROPODOUS EMBRYO: absent (0), present (1) (S&L-079; R99-118)
070. EMBRYO AXIS: straight (0), curved (1) (S&L-080; R99-119; M03-077; P15-210)
071. SEEDLINGS: dicotyledonous (0), monocotyledonous (1) (S&L-081; R99-120; P15-211)
072. SEEDLING TYPE: a (0), b (1), c (2), d (3) (S&L-082; R99-121)
073. RADICLE: absent (0), short lived (1), persistent (2) (S&L-083; R99-122; P15-213)
074. COLLAR: absent (0), present (1) (S&L-084; R99-123; M03-079; P15-214)
075. COTYLEDON TIP: non-haustorial (0), Haustorial (1) (S&L-085; R99-124; P15-215)
076. COTYLEDON SHEATH: absent (0), open (1), closed (2) (S&L-086; R99-125; M03-080; P15-216)

077. COTYLEDON LIGULE: absent (0), open (1), closed (2) (S&L-087; R99-126; M03-082 modified; P15-218 modified)
078. COTYLEDON LIMB: absent (0), present (1) (S&L-088 modified; R99-127; M03-081; P15-217)
079. MEIOSIS: normal (0), postreductional (1) (S&L-089; M03-083; P15-219)
080. CENTROMERE: localized (0), diffuse (1) (S&L-090; M03-084; P15-220)
081. CHELIDONIC ACID: absent (0), present (1) (S&L-091 modified; P15-211)
082. STERIODAL SAPONINS: absent (0), present (1) (S&L-092 modified; P15-222)
083. CYANOGENIC COMPOUNDS: absent (0), present (1) (S&L-093 modified; M03-085; P15-223)
084. FLORAL UV: absorption (0), reflection (1) (S&L-097; M03-086; P15-091)
085. CLADODES: absent (0), present (1) (S&L-098 modified; R99-006; P15-007)
086. PACHYCAUL ROSETTE: undeveloped (0), well developed (1) (S&L-99 modified; R99-007; M03-002; P15-008)
087. RESUPINATE FLOWERS: absent (0), present (1) (S&L-100 modified; R99-049)
088. EMBRYOSAC DEVELOPMENT: monosporic (0), bisporic (1), tetrasporic (2) (S&L-101; R99-105; P15-179)
089. ROOT HAIRS: absent (0), present (1) (R99-002 modified; P15-002)
090. DIFFUSE SECONDARY GROWTH: absent (0), present (1) (R99-008; M03-003; P15-009)
091. SECONDARY THICKENING MERISTEM: absent (0), present (1) (R99-009; R02-003; P15-012)
092. SILICA BODY SHAPE: druse (0), hat (1), trough (2), spherical (3), cubic (4) (R99-017; M03-008 modified; P15-027)
093. SILICA SAND: absent (0), present (1) (R99-018; M03-009; P15-028)
094. SILICA: absent (0), present (1) (R99-019; M03-010; P15-024)
095. CHLORENCHYMA: lobed (0), pegged (1) (R99-020; M03-011; P15-030)
096. BIG STARCH GRAINS (IN THE MATURE EMBRYO SAC): absent (0), present (1) (R99-021; M03-012; P15-031)
097. PETIOLE ASSIMILATING TISSUE: peripheral (0), diffuse (1), with veins (2) (R99-035; P15-053)
098. MESOPHYLL PARENCHYMA BUTTRESSES: absent (0), present (1) (R99-037; M03-023; P15-056)
099. SUBSIDIARY OBLIQUE DIVISION: absent (0), present (1) (R99-040 modified; M03-026 modified; P15-059)
100. EPICUTICULAR WAX: absent (0), 3D (1), rod- or filament-like (2), scale-like (3), amorphous (4) (R99-041)
101. SCALE DISTRIBUTION: random (0), Convallaria (1) (R99-042)
102. ROD FORM: plain (0), sculptured (1), Strelitzia (2) (R99-043)
103. 3-D SHAPE: irregular (0), horns (1) (R99-044)
104. AMORPHOUS PATTERN: nets (0), lines (1), crust (2) (R99-045)
105. ARISTLOCHIA WAX: absent (0), present (1) (R99-046)
106. OUTER PERIANTH: absent (0), present (1) (R99-051 modified; M03-026 modified; P15-101)
107. INNER PERIANTH: absent (0), present (1) (R99-052 modified; M03-030 modified; P15-105)
108. OUTER PERIANTH FORM: sepaloid (0), petaloid (1) (R99-054; M03-032; P15-102)
109. INNER PERIANTH FORM: sepaloid (0), petaloid (1) (R99-055; M03-033; P15-106)
110. INNER STAMENS: zero (0), one (1), two (2), three (3), many (4) (R99-059; R02-031 modified; P15-117)
111. OUTER STAMENS: zero (0), one (1), two (2), three (3), many (4) (R99-060; R02-030; M03-034; P15-111)
112. SPIRAPERTURATE: absent (0), present (1) (R99-073; M03-047)

113. POLLEN APERTURE TYPE: sulcate (0), synsulcate (1), porate (2), trichotomosulcate (3), ulcerate (4), clypeate (5), spiraperturate (6), cryptoaperturate (7), omniaperturate (8), zonosulcate (9) (R99-074; R02-047 modified; M03-048 modified; P15-143)
114. SULCI: one (0), two (1), three (2), poly (3) (R99-075)
115. EXINE: present (0), vestigial (1) (R99-076)
116. SCROBICULI: absent (0), present (1) (R99-077; M03-049; P15-140)
117. TECTUM ORNAMENTATION: tectate (0), semitectate (1), intectate (2), atectate (3) (R99-080; M03-052; P15-144)
118. STIGMA BRANCHING: simple (0), branched (1) (R99-086; M03-056; P15-152)
119. PSEUDOMONOMERY: absent (0), present (1) (R99-087; M03-057; P15-154)
120. INTRAOVARIAN MUCILAGE: absent (0), present (1) (R99-089; P15-156)
121. OVULES PER LOCULE: one (0), many (1) (R99-090; R02-057; M03-058; P15-157)
122. SINGLE OVULE: basal (0), apical (1), median (2) (R99-091; M03-059 P15-158)
123. PLACENTATION: laminar (0), marginal (1) (R99-092; M03-060; P15-159)
124. SYNCARPOUS PLACENTA: axile (0), parietal (1), free central (2) (R99-093; M03-061; P15-160)
125. INTEGUMENT TANNIN: absent (0), present (1) (R99-098; P15-173)
126. MICROPYLE: endostomic (0), exostomic (1) (R99-099; M03-065; P15-163)
127. OVULES: normal nucellus (0), massive nucellus (1) (R99-101; M03-067; P15-175)
128. NUCELLUS EPIDERMAL CELLS: elongated (0) square (1) (R99-102; M03-176; P15-176)
129. NUCELLUS SHAPE: ovate (0), elliptical (1) (R99-103; P15-177)
130. HELOBIAL ENDOSPERM: normal (0), haemodore type (1) (R99-108; P15-183)
131. CHALAZOSPERM: absent (0), present (1) (R99-110; M03-073; P15-185)
132. DERMAL PERISPERM: absent (0), present (1) (R99-111; P15-186)
133. SUBDERMAL PERISPERM: absent (0), present (1) (R99-112; P15-187)
134. ENDOSPERM IN MATURE SEED: absent (0), present (1) (R99-113; P15-181)
135. SCLERENHYMA SURROUNDING ENDODERMIS: absent (0), present (1) (R02-004)
136. ROOT CRYSTALS: absent (0), styloids present in suberized cells (1) (R02-006)
137. DIMORPHIC HYPODERMIS: absent (0), present (1) (R02-007)
138. LEAVES: linear (0), broad (1) (R02-008)
139. LEAVES: not plicate (0), plicate (1) (R02-009)
140. LEAF BLADE: bifacial (0), leaf blade equitant or terete (1), semiequitant (2) (R02-010)
141. TWO PROMINENT LATERAL VEINS: absent (0), present (1) (R02-011)
142. HAIRS: absent or unbranched (0), branched (1) (R02-012)
143. SECRETORY CANALS: absent (0), present (1) (R02-013)
144. MUCILAGE CANALS: absent (0), present (1) (R02-014)
145. SCLERENCHYMA GIRDERS: absent (0), present (1) (R02-015)
146. ALOIN CELLS: absent (0), present (1) (R02-016)
147. BULLIFORM CELLS: absent (0), present (1) (R02-017)
148. STYLOIDS: absent (0), present (1) (R02-019; P15-019)
149. SIMPLE RACEMOSE INFLORESCENCE: raceme (0), head (1), spadix (2), spike (3), umbel (4), thyrsi (5) (R02-021 modified; P15-096)
150. INFLORESCENCE AXIS: leafless (0), leafy or with scale leaves (1) (R02-022)
151. FLOWERS: not articulating (0), articulating from pedicels (1) (R02-023)
152. TEPALS: free (0), connate (at least at the base) (1) (R02-025)
153. CORONA APPENDAGES: absent (0), present (1) (R02-027)
154. HOLLW HAIRS ON TEPALS: absent (0), present (1) (R02-028)
155. GYNOSTEMIUM: absent (0), present (1) (R02-029)
156. STAMENS: equal in length (0), dimorphic (1) (R02-032)
157. ADNATE OUTER STAMENS: absent (0), present (1) (R02-033; P15-114)
158. CONNATE STAMEN FILAMENTS: absent (0), present (1) (R02-034; M03-036)
159. STAMINODIA: absent (0), present (1) (R02-035; M03-035)

160. FILAMENTS: straight, glabrous (0), with struma or hairs (1) (R02-036)
161. ANTHR TISSUE EXTENSION BEYOND THE LOCULES: absent (0) present (1) (R02-037)
162. FILAMENTS: straight (0) geniculate (1) (R02-038)
163. ANDROECIUM: symmetrical (0) asymmetrical (1) (R02-039)
164. ANTHR APPENDAGES: absent (0) present (1) (R02-041)
165. ANTHR DEHISCENCE: not apical (0) apical (1) (R02-043)
166. EXTRA POLLEN MATERIAL: absent (0), mucilaginous chains (1), mucilaginous tubes (2), massulae and pollinia (3) (R02-045 modified; P15-135)
167. EXINE PROTUBERANCES: absent (0), spinulose-gemmate (1) (R02-046; M03-091; P15-139)
168. POLLEN: sulcate (0) inaperturate or diffuse sulcate (1) (R02-048)
169. PORATE POLLEN OPERCULUM: absent (0), present (1), coarse granules (2) (R02-049 modified; M03-93; M15-137)
170. OVARY: trilocular (0) unilocular (1) (R02-052)
171. EPIGYNOUS ORARY BEAK: absent (0) present (1) (R02-053)
172. STYLE: apically inserted (0) gynobasic (1) (R02-054)
173. STYLE: hollow (0) solid (1) (R02-055; M03-090; P15-153)
174. SEEDS: small (0) large (1) (R02-061)
175. TESTA: not pitted (0) pitted (1) (R02-062)
176. SEED COAT: not hairy (0) hairy (1) (R02-063)
177. TELOMERE REPEAT SEQUENCE: present (0) absent (1) (R02-065)
178. SIEVE TUBE PLASTIDS: p11c (1) pllcs (2) pllcs9 (3) (M03-006)
179. INFLORESCENCE: solitary flower (0) cymose (1) panicle (2) raceme (3) spike (4) spadix (5) head (6) (M03-027)
180. PERIANTH CONNATION: absent (0) present (1) (M03-031)
181. THECAE PER ANTHR: two (0) one (1) (M03-041)
182. SPORANGIA PER THECA: two (0) one (1) (M03-042)
183. RHIZOIDS: absent (0) present (1) unnamed state (2) (M03-078)
184. FLOWER LONGEVITY: many days (0) one day (1) (M03-087)
185. SHOOT APEX: normal (0) sunken (1) (M03-088)
186. STYLAR APPENDAGES: absent (0) present (1) (M03-089)
187. EXOTHECIUM: absent (0) present (1) (M03-092)
188. GRASS 28 KB INVERSION: absent (0) present (1) (M03-094)
189. GRASS 6 KB INVERSION: absent (0) present (1) (M03-095)
190. GRASS TRNL INVERSION: absent (0) present (1) (M03-096)
191. ORF2280 deletion IR 6 KB: undeleted (0) deleted (1) (M03-097)
192. RADIAL LEAF TIP: absent (0), present (1) (P15-010)
193. PRIMARY THICKENING MERISTEM: absent (0), present (1) (P15-011)
194. STEMS SCLERIFIED PRIMARY TISSUE: absent (0), minor (1), extensive (2) (P15-016)
195. DRUSES: absent (0), present (1) (P15-020)
196. GROOVED RAPHIDES: absent (0), present (1) (P15-022)
197. RAPHIDE CANALS: absent (0), present (1) (P15-023)
198. SILICA COARSE AGGREGATES: absent (0), present (1) (P15-025)
199. SILICA LOCATION: epidermis (0), subepidermal sclerenchyma (1), bundle sheath sclerenchyma (2) (P15-029)
200. LEAF ORGANIZATION: simple (0), palmately compound (1), pinnately compound (2) (P15-033)
201. LEAF SHEATH: absent (0), tubular open (1), tubular closed (2) (P15-038)
202. ADAXIAL LIGULE: absent (0), present (1) (P15-041)
203. ABAXIAL LIGULE: absent (0), present (1) (P15-042)
204. LATERAL LIGULE: absent (0), present (1) (P15-043)

205. BRACTEOLE: absent (0), present (1) (P15-044)
206. FIRST TEPAL BRACTEOLATE: absent (0), present (1) (P15-045)
207. BRACTEOLE POSITION: abaxial (0), adaxial (1) (P15-046)
208. LEAF AIR CANALS SEPTATE: absent (0), present (1) (P15-055)
209. SIEVE TUBE PLASTIDS WITH STARCH (S): absent (0), present (1) (P15-060)
210. SIEVE ELEMENT PLASTID WITH STARCH PROTEIN CRYSTALS AND FILAMENTS (P1cfs): absent (0), present (1) (P15-061)
211. SIEVE ELEMENT PLASTID WITH PROTEIN CRYSTALS ONLY (P2c): absent (0), present (1) (P15-062)
212. SIEVE ELEMENT PLASTID WITH STARCH GRAINS PLUS CUNEATE CRYSTALS (P2cs): absent (0), present (1) (P15-063)
213. SIEVE ELEMENT PLASTID WITH STARCH GRAINS PLUS POLYGONAL CRYSTALS (P1cs): absent (0), present (1) (P15-064)
214. SIEVE ELEMENT PLASTID WITH CRYSTALS AND FILAMENTS (P2cf): absent (0), present (1) (P15-065)
215. SIEVE ELEMENT PLASTID WITH CUNEATE CRYSTALS FILAMENTS AND STARCH (P2cfs): absent (0), present (1) (P15-066)
216. SIEVE ELEMENT PLASTID PROTEIN CRYSTALS WITH CUNEATE AND ADDITIONAL LOOSE CRYSTALS (P2ccl): absent (0), present (1) (P15-067)
217. SIEVE ELEMENT PLASTID PROTEIN CRYSTALS WITH ONE OR THREE ORTHOGONAL AND MANY CUNEATE CRYSTALS (P2cco): absent (0), present (1) (P15-068)
218. SIEVE ELEMENT PLASTID PROTEIN CRYSTALS WITH A SINGLE LARGE LOOSELY PACKED POLYGONAL CRYSTAL AND MANY CUNEATE ONES (P2ccp): absent (0), present (1) (P15-069)
219. SIEVE ELEMENT PLASTID WITH STARCH GRAINS PLUS CUNEATE AND POLYGONAL CRYSTALS (P2ccps): absent (0), present (1) (P15-070)
220. SIEVE ELEMENT PLASTID WITH CUNEATE AND LOOSE CRYSTALS AND FILAMENTS (P2cclf): absent (0), present (1) (P15-071)
221. SIEVE ELEMENT PLASTID WITH ORTHOGONAL AND CUNEATE CRYSTALS AND FILAMENTS (P2ccof): absent (0), present (1) (P15-072)
222. SIEVE ELEMENT PLASTID WITH LOOSELY PACKED POLYGONAL AND CUNEATE CRYSTALS AND FILAMENTS (P2ccpf): absent (0), present (1) (P15-073)
223. EPICUTICULAR WAX: absent (0), present (1) (P15-074)
224. EPICUTICULAR FILMS: absent (0), present (1) (P15-075)
225. EPICUTICULAR LAYERS AND CRUSTS: absent (0), present (1) (P15-076)
226. EPICUTICULAR CRYSTALLOIDS: absent (0), present (1) (P15-077)
227. EPICUTICULAR GRANULES: absent (0), present (1) (P15-078)
228. EPICUTICULAR PLATELETS AND PLATES: absent (0), present (1) (P15-079)
229. EPICUTICULAR PLATELET ORIENTATION: random (0), rosettes (1), parallel (2) (P15-080)
230. EPICUTICULAR PLATELETS AND PLATES MORPHOLOGY: entire platelets (0), irregular platelets (1), membranaceous platelets (2), plates (3) (P15-081)
231. EPICUTICULAR RODLETS: absent (0), present (1) (P15-082)
232. EPICUTICULAR RODLETS MORPHOLOGY: polygonal (0), terete or hooked (1), coiled (2), transversely ridged (3) (P15-083)
233. ORIENTATION PATTERNS OF RODLETS AND TUBULES: clusters of tubules (0), clusters of rodlets (1), longitudinally aggregated rodlets (2) (P15-084)
234. EPICUTICULAR THREADS: absent (0), present (1) (P15-085)
235. EPICUTICULAR TUBULES: absent (0), present (1) (P15-086)
236. EPICUTICULAR TUBULES MORPHOLOGY: nonacosanol tubules (0), diketone tubules (1) (P15-087)

237. LOCALLY RESTRICTED ORIENTATION PATTERNS: random (0), clustered (1) (P15-088)
238. STOMATAL CHIMNEYS: absent (0), present (1) (P15-089)
239. FLOWERS RUBBISH: solitary (0), inflorescence (1) (P15-093)
240. ULTIMATE INFLORESCENCE UNIT: with terminal flower (0), without terminal flower (1) (P15-094)
241. MAIN INFLORESCENCE AXIS: with terminal flower (0), without terminal flower (1) (P15-095)
242. FLOWER FUSION: hypogynous (0), perigynous (1), epigynous (2) (P15-098)
243. DELIQUESCENT FLOWERS: absent (0), present (1) (P15-099)
244. FIRST TEPAL POSITION: adaxial (0), abaxial (1) (P15-100)
245. OUTER PERIANTH CONNATION: absent (0), present (1) (P15-103)
246. MONOSYMETRIC OUTER PERIANTH: absent (0), present (1) (P15-104)
247. INNER PERIANTH CONNATION: absent (0), present (1) (P15-107)
248. MONOSYMETRIC INNER PERIANTH: absent (0), present (1) (P15-108)
249. MONOSYMETRIC OUTER STAMINAL WHORL: absent (0), present (1) (P15-112)
250. OUTER ANDROECIAL WHORL: epitepalous (0), hypogynous (1) (P15-113)
251. OUTER STAMINODIA: absent (0), present (1) (P15-115)
252. OUTER CONNATE STAMEN FILAMENTS: absent (0), present (1) (P15-116)
253. MONOSYMETRIC INNER STAMINAL WHORL: absent (0), present (1) (P15-118)
254. INNER ANDROECIAL WHORL: epitepalous (0), hypogynous (1) (P15-119)
255. ADNATE INNER STAMENS: absent (0), present (1) (P15-120)
256. INNER STAMINODIA: absent (0), present (1) (P15-121)
257. INNER CONNATE STAMEN FILAMENTS: absent (0), present (1) (P15-122)
258. APERTURE NUMBER: one (0), two (1), three (2), four to many (3), none (4), convergent (5) (P15-136)
259. EXINE: present (0), vestigial (1) (P15-138)
260. GYNOECIUM APPENDAGE LOCATION: ovary (0), style (1) (P15-148)
261. STYLE FUSION (IN SYNCARPOUS TAXA): absent (0), present (1) (P15-149)
262. ZIGZAG MICROPYLE: absent (0), present (1) (P15-164)
263. MICROPYLAR COLLAR: absent (0), present (1) (P15-165)
264. MICROPYLE ORIENTATION: hypotropous (0), epitropous (1), pleurotropous (2) (P15-166)
265. HYPOTROPOUS OVULES: vertical (0), pendant (1), horizontal (2) (P15-167)
266. EPITROPOUS OVULES: vertical (0), pendant (1), horizontal (2) (P15-168)
267. PLEUROTROPOUS OVULES: inwardly curved (0), outwardly curved (1) (P15-169)
268. EMBRYO POSITION: embedded in nutritive tissue (0), lateral (1) (P15-170)
269. EMBRYOSAC STARCH: small grains (0), large grains (1) (P15-172)
270. SYNCARPOUS FRUIT: dehiscent (0), indehiscent (1) (P15-189)
271. VENTRICIDAL CAPSULES: absent (0), present (1) (P15-190)
272. LOCULICIDAL CAPSULES: absent (0), present (1) (P15-191)
273. SEPTICIDAL CAPSULES: absent (0), present (1) (P15-192)
274. PORICIDAL CAPSULES DERIVED IN NUMEROUS WAYS: absent (0), present (1) (P15-193)
275. FLESHY EXOCARP: absent (0), present (1) (P15-194)
276. FLESHY MESOCARP: absent (0), present (1) (P15-195)
277. FLESHY ENDOCARP: absent (0), present (1) (P15-196)
278. STROPHIOLE: absent (0), present (1) (P15-200)
279. CARUNCULE: absent (0), present (1) (P15-201)
280. ELAISOME: absent (0), present (1) (P15-202)
281. HILUM SHAPE: circular (0), oblong (1) (P15-203)
282. PODIUM: absent (0), present (1) (P15-204)
283. POSTAMENT: absent (0), present (1) (P15-205)

- 284. EPISTASE: absent (0), present (1) (P15-206)
- 285. HYPOSTASE: absent (0), present (1) (P15-207)
- 286. RUMINATE ENDOSPERM: absent (0), present (1) (P15-208)
- 287. FERULIC ACID IN THE CELL WALL: absent (0), present (1) (P15-224)
- 288. ALUMINIUM ACCUMULATION: absent (0), present (1) (P15-225)
- 289. ALKALOIDS: absent (0), present (1) (P15-226)
- 290. FRUCTANS: absent (0), present (1) (P15-227)