Supporting Information for "Fruit evolution and diversification in campanulid angiosperms"

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Reconstruction of campanulid fruit type evolution

Our correlated paths model inferred the dehiscent, dry, multiple-seeded (capsule) combination, as the ancestral fruit type in Campanulidae, which is somewhat surprising given that this state combination is not widely distributed within the group. This combination was also inferred to be the ancestral fruit type for nearly all of the earliest campanulid divergences, including each of the smaller clades, such as the Escallionaceae (*s.l.*), Bruniales, and the Paracryphiaceae. In general, transitions out of this ancestral fruit configuration were reconstructed to have occurred after the origin and early diversification of the primary campanulid clades. The one exception was the Aquifoliales, which was inferred to have gained fleshiness early, likely through a path that first involved the loss of dehiscence (Fig. 1-2). Indehiscent, fleshy, multiple seeded fruits were retained within the Aquifoliaceae, where this is the only fruit type observed in extant members of the group. There was a reduction to a single seed inferred along the branch leading to Cardiopteridaceae-Stemonuraceae. The winged samaras that arose later within the Cardiopteridaceae originated via the loss of fleshiness (Fig. 1-2).

The initial divergences within the Asterales were reconstructed as being dehiscent, dry, multiple-seeded (capsule) fruits. Capsules later gave rise to several fleshy-fruited lineages through an intermediate step that likely first involved the loss of dehiscence. For example, within the Campanulaceae (*s.l.*) the loss of dehiscence facilitated several gains of fleshiness within the Hawaiian lobelioids (the most inclusive clade that includes *Cynea*, *Clermontia*, and *Delissea*) as well as within a small clade of South American lobelioids (the most inclusive clade that includes *Centropogon* and *Burmeistera*). The fleshy fruits within the Goodeniaceae were also likely derived from ancestors with indehiscent, dry, multi-seeded (IDM) fruits, a condition that appears to have been retained in several smaller clades within *Scaevola* (Fig. 1-2). The loss of dehiscence from the ancestral capsule condition is also likely to have been the intermediate step along the path that led to the emergence of indehiscent, dry, single-seeded (achene) fruits, a condition reconstructed as the ancestral state of the Calyceraceae-Asteraceae clade. Achenes have largely been retained within this clade, with very few gains of fleshiness found within the highly diverse Asteraceae (with exceptions being *Chrysanthemoides spp.* and *Tilesia baccata*).

The initial divergences within the Apiales were also confidently reconstructed as being dehiscent, dry, and multi-seeded. Previous work had suggested a fleshy fruit type as the likeliest ancestral condition for Apiales (Chandler and Plunkett, 2004) based on the first diverging lineages being predominately fleshy-fruited (i.e., Pennantiaceae, Toricelliaceae, and Griseliniaceae). Our analysis implies that the fleshiness within these clades is derived, and that the capsule fruits of the more nested Pittosporaceae were retained from the common ancestor of the Apiales (Fig. 1-2). The ancestral fruit type for the clade that comprises the bulk of the Apiales (e.g. Araliaceae-Myodocarpaceae-Apiaceae) was inferred to be an indehiscent, dry, multi-seeded fruit, with the gain of fleshiness occurring along the branch leading to the Araliaceae (Fig. 1-2). The reduction to single-seeded mericarps in this clade was inferred to have occurred at least three times: once along the branch leading to the Hydrocotyloideae, once along the branch leading to *Myodocarpus* within the Myodocarpaceae, and once along the branch leading to the Apiaceae (Fig. 1-2).

The first Dipsacales also likely had capsules, a condition maintained only in the Diervillaceae, an early diverging clade within the Caprifoliaceae *sensu lato*. One shift to fleshy fruits was at the base of the Adoxaceae, which is reconstructed as a berry (presumably with the formation of endocarp tissue). This condition was maintained in the Adoxoideae (containing *Sambucus*, *Adoxa*, *Tetradoxa*, and *Sinadoxa*), but reduction to a single seed marked the origin of *Viburnum* (Fig. 1-2). The first Caprifoliaceae *s.l.* are inferred here to have had capsule fruits, as in modern Diervilleae. There was a shift to a berry in the Caprifolieae (containing *Leycesteria, Triosteum, Symphoricarpos, and Lonicera*), and the achene fruit evolved on the line leading to the remaining lineages (including Linnaeeae, Morinaceae, Valerianaceae, and Dipsacaceae) (Fig. 1-2).

The ancestral states inferred under the multistate model are largely in agreement with the reconstructions described above, including the ancestral fruit type of campanulids being a capsule (Fig. S1). The disagreements occur largely as a consequence of transitions among the different states not being restricted in the multistate model. In other words, in the multistate model transitions among all fruit types can occur in a single step, even when these entail multiple underlying changes. For example, in the case of the evolution of the achene (mericarps) from a capsule within the Apiales, the correlated paths model inferred three separate origins of "achene" fruits within the Araliaceae-Myodocarpaceae-Apiaceae clade, which was the result of reducing to a single-seed from an ancestor that was indehiscent, dry, and multiple-seeded (or the IDM fruit type), a character state not observed in extant Apiales. By contrast, the multistate model inferred a single origin of the achene within this clade, largely as a consequence of a non-zero probability of a transition from a capsule to an achene occurring in a single step.

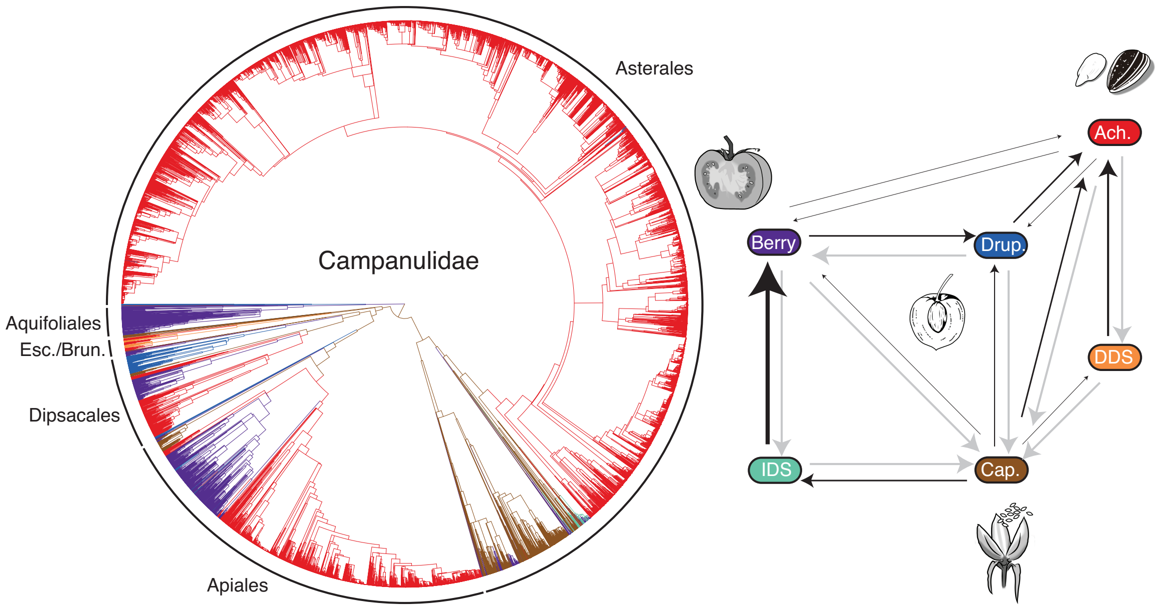

Figure S1. Time-calibrated phylogeny of 8,911 species of Campanulidae (campanulid amgiosperms) taken from a maximum likelihood (ML) analysis based on a combined analysis of 11 chloroplast genes and one nuclear gene. The major clades of campanulids are labeled; Esc/Brun represents the Escalloniales and the Bruniales. Joint reconstructions of the likeliest fruit type are based on parameters estimated from the multistate model, which only allowed direct changes between any fruit type (drawings of the four main fruit types – achene, berry, capsule, and drupe – were provided by Maxwell Rupp). Transitions between each character state are shown, with the thickness of the arrows corresponding to the rates (i.e., thicker arrows denoting higher rates).

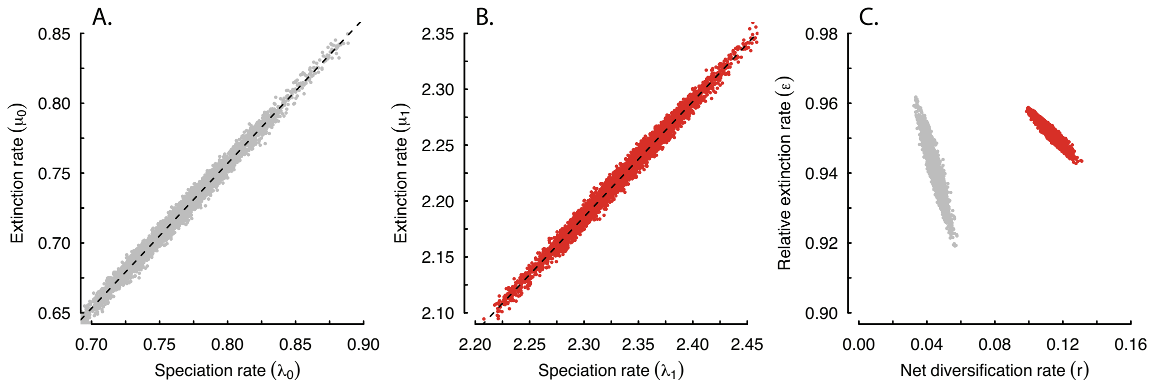

Figure S2. The joint posterior probability distributions of the speciation and extinction parameters from the BiSSE model. For both non-achene (A) and achene (B) lineages there was a strong positive association between speciation (λ) and extinction (μ). (C) The non-independence of these parameters also had a strong influence on the relationship between the relative extinction rate ($\varepsilon=\mu/\lambda$) and net diversification rate ($r=\lambda-\mu$).

Supplementary References

Chandler, G.T., and G.M. Plunkett. 2004. Evolution in Apiales: nuclear and chloroplast markers together in (almost) perfect harmony. Botanical Journal of the Linnean Society 144, 123-147.