

Genomic evidence for convergent evolution of gene clusters for momilactone biosynthesis in land plants

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The biosynthetic genes of some specialized plant metabolites appear to be clustered in the genomes of higher plants. Momilactones are defense compounds produced in rice and barnyard grass by family-conserved biosynthetic gene clusters (BGCs).

We sequenced the genome of *Calohyllum plumiforme*, a momilactone-producing nonvascular bryophyte, and showed that it also contains a functionally similar momilactone BGC distinguished by its lack of synteny with the clusters found in vascular plants. The expression of the *Calohyllum* biosynthetic genes in tobacco demonstrated their role in momilactone A production.

This is the first report of a BGC for a specialized metabolite in bryophytes. Our findings indicate that the momilactone clusters present in three different plant species may have evolved independently via convergent evolution.

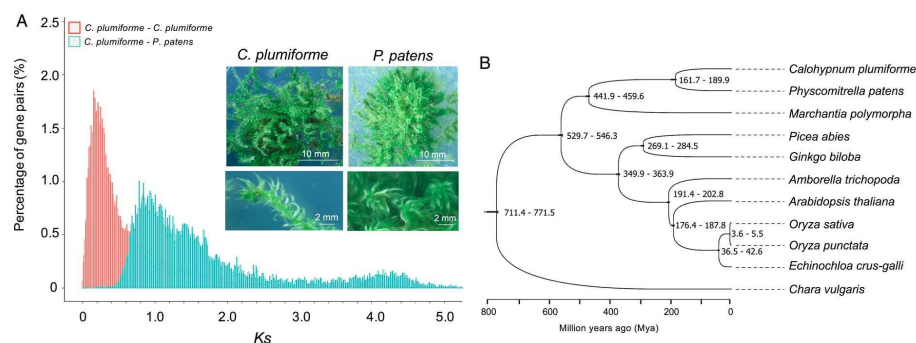


Fig. 1 | Evolution of the *Calohyllum* genome.
(A) Graph showing the Ks distribution of paralogous gene pairs of *C. plumiforme* and orthologous gene pairs between *C. plumiforme* and *P. patens*.
(B) Phylogenetic trees of showing the relation between of bryophytes and seed plants based on single-copy genes of their chloroplast genomes.

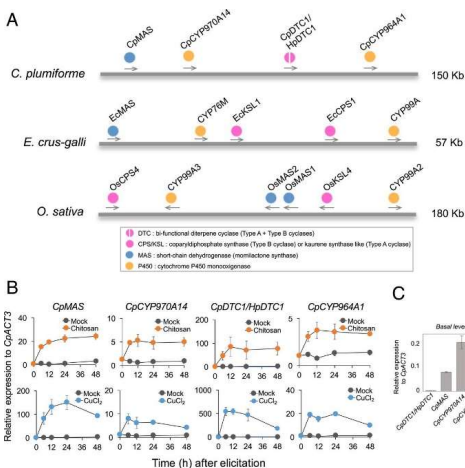


Fig. 2 | The putative gene cluster for momilactone biosynthesis in *C. plumiforme*.
(A) The genomic synteny of the BGCs for momilactone formation in plants. (B) Time course gene-expression profiles of the four genes found in the momilactone BGC after the treatment of CuCl_2 or chitosan. The data shown were normalized by comparison to the expression of the housekeeping gene *CpACT3*. (C) Comparison of basal expression levels of the four genes in the cluster. The expression data represent the mean \pm SD of three biological replicates with independent elicitor treatments to *C. plumiforme* gametophytes.

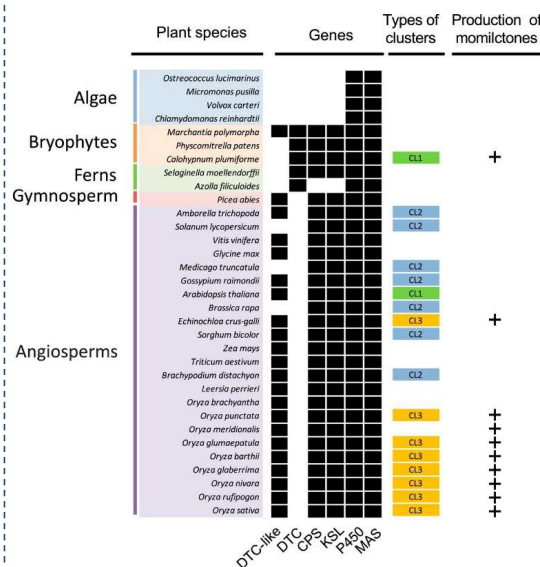


Fig. 3 | Genome-wide identification of the clustered genes for momilactone biosynthesis in plants.
Black boxes represent existence of the genes in the corresponding plant genome. Types of gene clustering: CL1, DTC, or DTC-like type of terpene synthase gene + P450 + MAS; CL2, one type of terpene synthase gene (CPS or KS or DTC or DTC-like) + P450 + MAS; CL3, two types of terpene synthase genes (CPS and KSL) + P450 + MAS. Momilactones were only detected in the species with CL1 or CL3 gene clusters.