

Genetic and metabolomic analysis of pollen cone color polymorphism in *Abies fraseri*

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Abies comprises 47 species native to boreal and temperate coniferous forests of the Northern Hemisphere and is the preferred genus for Christmas trees worldwide. Fraser fir (*Abies fraseri*) is the most popular species commercially available throughout the eastern US and is the primary focus of the Christmas Tree Genetics (CTG) program at North Carolina State University. Pollen and seed cones across conifers display diverse pigmentation, ranging from yellow and red to green, blue, and purple. Metabolomic surveys of 27 coniferous species—including *Abies*, *Picea*, *Pinus*, *Pseudotsuga*, and *Tsuga*—identified only four anthocyanins in their cones: cyanidin 3-glucoside, delphinidin 3-glucoside, peonidin 3-glucoside, and petunidin 3-glucoside, with cyanidin and delphinidin responsible for red and purple colorations. In Fraser fir, seed cones are characteristically dark blue while pollen cones range from yellow to red; yet the genetic mechanisms underlying this variation remain unknown. We hypothesize that sequence variation in promoters of genes regulating anthocyanin accumulation—particularly MYB transcription factors—drives pollen cone color polymorphism. To test this hypothesis, we conducted RNA-seq on nearly dehiscent pollen cones from 16 trees representing four elite Fraser fir genotypes with distinct pollen cone color phenotypes. Anthocyanin metabolites in the same samples will be analyzed via UPLC–MS–PDA. The promoters of differentially expressed genes associated with metabolites responsible for red and purple coloration will be analyzed for sequence and motif differences between genotypes. This work supports CTG's mission to develop cisgenic Fraser fir lines with enhanced pathogen resistance, climate resilience, post-harvest needle retention, and aroma. This will identify genetic targets for ornamental varieties with purple or variegated needles and can be utilized as visual markers for genetic engineering. Given mounting pressures from pathogens, insects, climate change, and anthropogenic disturbance, these advances are critical for sustaining both the species and the NC Christmas tree industry.