6 Maple Variety Breeding and Genetic Improvement

6.1 Traditional breeding and molecular marker-assisted breeding

The selection and breeding of maple varieties have long relied primarily on traditional cross-breeding and seedling selection, screening based on phenotypic traits such as leaf color, tree form, and growth rate. However, leaf color traits are regulated by multiple genes and are easily influenced by environmental conditions, making traditional breeding cycles long and efficiency relatively low. In actual breeding processes, it often takes several years or even more than a decade from cross-pollination to the flowering and fruiting of seedlings, and leaf color expression requires many years of observation to confirm its stability. Furthermore, traditional breeding struggles to precisely select genes related to leaf color, and the inheritance of excellent traits involves considerable uncertainty, increasing the difficulty and cost of breeding efforts.

In recent years, with the development of molecular marker technologies, DNA molecular marker-based (such as SSR, SNP) assisted breeding has greatly improved selection efficiency. By constructing genetic linkage maps of maple, researchers have mapped QTL loci associated with leaf color, providing a basis for early screening of target traits (Zhang et al., 2023). Molecular marker-assisted breeding allows for genotype identification at the seedling stage using small amounts of leaf tissue, eliminating the need to wait many years for phenotypic observation and significantly shortening the breeding cycle. For example, molecular markers closely linked to the UFGT gene have been developed in red maple, enabling rapid identification of red-leaf genotypes and accelerating the breeding process of superior varieties (Figure 8) (Chen et al., 2019). Currently, molecular markers for several important ornamental traits in maple have been successively developed, laying a solid foundation for the genetic improvement of maple.

6.2 Application prospects of gene editing technology in leaf color improvement

With the popularization of genome sequencing technology, the genomes of various maple species have been resolved, laying the foundation for gene editing. Technologies such as CRISPR/Cas9 offer the possibility of precisely modifying genes related to leaf color. By knocking down or activating specific transcription factors (such as MYB, bHLH) or structural genes (such as DFR, ANS), the synthesis and accumulation of anthocyanins can be directionally regulated, thereby altering leaf color expression (Recinos and Pucker, 2023). Unlike random mutagenesis, gene editing technology enables site-specific modification of target genes, avoiding the linkage introduction of undesirable traits and greatly improving breeding efficiency and precision. Currently, this technology has been successfully applied in model plants such as Arabidopsis and rice for regulating anthocyanin metabolism, providing important references for the genetic improvement of maple.

Furthermore, gene editing can also be used to enhance the adaptability of maple to environmental stresses, such as improving drought tolerance or disease resistance, allowing excellent leaf color traits to be stably expressed in complex urban environments. Stress factors in urban environments, such as drought, soil salinization, and air pollution, often lead to premature leaf senescence and disrupted pigment metabolism, affecting the red leaf landscape effect. By editing transcription factors or functional genes related to stress response, the stress resistance of maple can be enhanced, ensuring normal color change under adverse conditions. Currently, the genetic transformation system for maple is not yet fully developed, but related research is progressing. Methods such as Agrobacterium-mediated transformation and particle bombardment have been successfully applied in some Aceraceae species. With the improvement of genetic transformation efficiency and the optimization of gene editing technologies, precise improvement and directional breeding of maple leaf color traits are expected in the future.

6.3 Promotion and adaptability evaluation of superior varieties

The promotion and application of new varieties require comprehensive consideration of their ecological adaptability, ornamental stability, and cultivation management requirements. Different maple varieties respond differently to environmental factors such as light, temperature, and soil pH, which directly affects leaf color expression and growth vigor. For example, some red-leaf varieties show reduced anthocyanin accumulation and greener leaves under insufficient light; while yellow-leaf varieties may shed leaves prematurely under high