

Remodeling of Photosynthetic Membrane Lipids in Plants: Insights from *Perilla Frutescens* and Tomato

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Abstract

Lipid metabolism plays a central role in plant stress tolerance and developmental programming, with direct implications for crop productivity and nutritional quality. This study integrated lipidomic approaches to investigate glycerolipid remodeling in two contexts: exogenous melatonin (MT) alleviation of cadmium (Cd) stress in tomato, and polar lipid dynamics during oil biosynthesis in developing *Perilla frutescens* cotyledons. In Cd-stressed tomato, MT application significantly improved growth and photosynthetic performance. Glycerolipidomic analysis revealed that MT counteracted Cd-induced declines in key lipids, including monogalactosyldiacylglycerol (MGDG), digalactosyldiacylglycerol (DGDG), sulfoquinovosyldiacylglycerol (SQDG), phosphatidylcholine (PC), and phosphatidylglycerol (PG). Notably, MT elevated the unsaturation index of total lipids and individual classes, increased the DGDG/MGDG and PC/PE ratios, and reduced Cd accumulation in leaves and roots. These changes preserved thylakoid membrane integrity and fluidity, thereby sustaining photosynthetic electron transport under Cd stress. In *Perilla frutescens*, a lipidomic analysis of developing perilla cotyledons (5, 15, and 25 days after anthesis) identified 147 molecular species across 10 polar lipid classes. During cotyledon maturation, total lipid and polar lipid contents declined, with PC showing the most pronounced decrease (65.8%), while lysophosphatidic acid (LPA) increased by 62.4% at the late stage. Major species such as MGDG C36:6 and DGDG C36:6 decreased significantly, and the unsaturation index of most polar lipids dropped, indicating a metabolic shift from membrane biogenesis to triacylglycerol (TAG) accumulation. Collectively, these findings highlight that targeted glycerolipid remodeling—whether induced by melatonin under heavy metal stress or occurring naturally during seed development—is a conserved strategy for optimizing membrane function and carbon partitioning. Understanding these lipid regulatory networks provides a foundation for enhancing stress resilience and oil quality in nutritionally important crops.

Keywords

Lipidomics, Melatonin, Cadmium Stress, *Perilla Frutescens*, Tomato, Glycerolipid Remodeling, Oil Biosynthesis