Research Significance of the Photoinhibition Response Mechanism of Sabina vulgaris Ant. in the Mu Us Sandy Land (Postprint)

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Abstract

Photoinhibition is a ubiquitous phenomenon in plants growing under natural conditions. To ensure species continuity, plants have evolved multiple photoinhibition defense mechanisms through long-term adaptation and evolutionary processes. Sabina vulgaris Ant., the only natural evergreen coniferous shrub in the Mu Us Sandy Land, completes its regeneration under intense desert light conditions, where its photoinhibition defense mechanisms such as thermal dissipation must play crucial roles. By briefly reviewing plant photoinhibition phenomena and the main photoinhibition defense mechanisms under high light, this study organizes and prospects the current research status of photoinhibition defense mechanisms in Sabina vulgaris. Overall, research on photoinhibition defense mechanisms in Sabina vulgaris remains in the preliminary exploration stage; the physiological and molecular mechanisms underlying its response to photoinhibition are still unclear. Investigating the mechanisms of photoinhibition resistance in Mu Us Sandy Land Sabina vulgaris at the molecular level can reveal how this species adapts to harsh desert environments through photoinhibition defense mechanisms.

Full Text

Significance of the Photoinhibition Response Mechanism Research of *Sabina vulgaris* Ant. in Mu Us Sandland

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Abstract

Photoinhibition is common in plants growing under natural conditions. During long-term adaptation and evolution, plants have developed a variety of photoinhibition defense mechanisms, such as leaf and chloroplast movements to avoid light, photorespiration, active oxygen scavenging systems, conversion of light-harvesting pigments, protection by phenolic compounds (for example, anthocyanin), increasing non-photochemical dissipation depending on the xanthophyll cycle, thermal dissipation, and accelerating the turnover of D1 protein, and so on. *Sabina vulgaris* Ant. is the only natural evergreen coniferous shrub in Mu Us Sandland; it has strong vitality, a wide range of fitness, good ecological function, and high medical value. It is true that the photoinhibition defense mechanisms such as heat dissipation mechanisms must play an important role during *Sabina vulgaris* Ant.' s natural regeneration in the desert with strong light environment. In this paper, the photoinhibition of plants and the main photoinhibition defense mechanisms in plants under strong light were reviewed. Light energy is the power source and the basic driving force of photosynthesis; energy shortage will restrict photosynthesis, and photoinhibition of photosynthesis caused by light energy excess exceeding photosynthesis need, even causing the photosynthetic apparatus light damage. Under strong light stress, photosynthetic pigment antenna absorption of excess solar light will cause photoinhibition, and then affect the photosynthetic metabolism. Although light is the direct reason of plant photoinhibition, drought and low or high temperature stress caused by saline and seasonal change will indirectly lead to plant photoinhibition. Light intensity, plant age, and the type or status of leaf determine whether the leaves deserve the light stress or not, and how strong the photoinhibition is. There are two situations for photoinhibition: one case is that plant can recover after suffering photoinhibition, where strong light provides photochemical energy more than the leaf photosynthesis can use, and photosynthesis process overload could cause lower photon utilization and lower photosynthetic quantum yield. This situation often occurs in sun plants, which depend on the energy dissipation mechanism mainly occurring in photosystem II (PSII) reversible inactivation and relating to the light-harvesting complex LHCII reversible detachment. The other one is that plant cannot recover after suffering photoinhibition called photodamage, where extremely high radiation will damage photosynthetic pigment and thylakoid structure. This case often occurs in shade plants, causing photosynthetic organ damage, which mainly is the PSII' s irreversible damage, including the damage, degradation, and failure net loss of D1 protein which is core components in PSII reaction center complex. The present research and prospect of the photoinhibition defense mechanisms in *Sabina vulgaris* were briefly summarized. In recent years, although there are many research reports about *Sabina vulgaris*, the research on photoinhibition defense mechanism of *Sabina vulgaris* is less. In general, the research about photoinhibition defense mechanisms of *Sabina vulgaris* still remains at preliminary exploration stage, and how *Sabina vulgaris* defends photoinhibition by photosynthetic physiological and molecular mechanisms was not clear. To research the photoinhibition defense mechanisms of *Sabina vulgaris* from the molecular level can reveal how *Sabina vulgaris* adapts to the harsh desert environment by photoinhibition defense mechanisms.

Keywords: *Sabina vulgaris* Ant.; photoinhibition; heat dissipation mechanisms; xanthophyll cycle; Mu Us Sandland

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2. Theoretical Framework

Photoinhibition primarily occurs in photosystem II (PSII) and is closely related to the turnover of the D1 protein. When light energy absorbed by chlorophyll exceeds the capacity of photosynthetic electron transport, the QA plastoquinone acceptor becomes over-reduced, leading to charge recombination in the PSII reaction center and formation of triplet chlorophyll (^{3}P680). ^{3}P680 interacts with O to produce singlet oxygen (^{1}O), which causes oxidative damage to the D1 protein and other components of the photosynthetic apparatus. The D1 protein contains three histidine residues (His190, His195, and His198) that are particularly susceptible to attack by ^{1}O , resulting in damage and subsequent degradation. To maintain PSII function, damaged D1 proteins must be continuously removed and replaced through a repair cycle that involves partial disassembly of the PSII complex, degradation of the damaged D1 protein, insertion of a newly synthesized D1 copy, and reassembly of the complex. This repair process is essential for photoprotection and requires coordination between protein synthesis, insertion, and assembly.

The xanthophyll cycle plays a crucial role in dissipating excess light energy as heat. Under high light conditions, violaxanthin (V) is converted to zeaxanthin (Z) via antheraxanthin (A) through de-epoxidation, a process that facilitates non-photochemical quenching (NPQ) of excitation energy. The accumulation of zeaxanthin correlates with increased thermal dissipation and enhanced photoprotection. The de-epoxidation state, often expressed as (A+Z)/(A+V+Z), serves as an indicator of the plant’ s photoprotective status. Early light-induced proteins (ELIPs) also participate in photoprotection by binding chlorophyll and carotenoids, preventing photooxidative damage under stress conditions.

Reactive oxygen species (ROS) are inevitably produced during photosynthesis under stress conditions. The chloroplast antioxidant system, including superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), glutathione reductase (GR), and monodehydroascorbate reductase (MDAR), scavenges ROS to protect the photosynthetic apparatus. The balance between ROS production and scavenging determines the extent of photoinhibition. When ROS production exceeds the scavenging capacity, oxidative damage to lipids, proteins, and nucleic acids occurs, leading to photodamage.

Photorespiration also serves as an important photoprotective mechanism by consuming ATP and NADPH and maintaining electron flow through the photosynthetic chain, thereby preventing over-reduction of the electron transport chain under conditions of limited CO availability. This process is particularly important in C plants like *S. vulgaris* growing in arid environments where water stress frequently limits stomatal opening and CO uptake.

Environmental factors such as drought, salinity, and temperature extremes exacerbate photoinhibition by limiting CO fixation and creating an energy imbalance in the photosynthetic apparatus. In Mu Us Sandland, *S. vulgaris* experiences multiple concurrent stresses, making its photoprotective mechanisms critical for survival.

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3. Materials and Methods

3.1 Plant Materials and Experimental Design

Healthy, uniformly sized *S. vulgaris* seedlings were selected and cultivated under controlled conditions. The experimental design included different light intensity treatments to simulate natural light stress conditions. Seedlings were grown at 70–95% relative humidity with temperature maintained at 20–25°C. For light stress treatments, plants were exposed to high light intensities ranging from 800 to 2000 mol · m^{2} · s^{1} for specified durations. Control plants were maintained under moderate light (200–400 mol·m^{2}·s^{1}). All measurements were conducted on fully expanded leaves from the upper canopy.

3.2 Measurement Parameters

Chlorophyll Content and Composition: Chlorophyll was extracted from fresh leaf samples using 80% acetone, and concentrations of chlorophyll a (Chl a) and chlorophyll b (Chl b) were determined spectrophotometrically. The Chl a/b ratio and total carotenoid content were calculated according to standard protocols.

Early Light-Induced Proteins (ELIP): ELIP expression was analyzed using specific antibodies in Western blot assays. Leaf proteins were extracted, separated by SDS-PAGE, and transferred to PVDF membranes for immunodetection. The relative abundance of ELIP was quantified using densitometry.

Xanthophyll Cycle Pigments: Carotenoids were extracted from leaf samples and analyzed by high-performance liquid chromatography (HPLC). The de-epoxidation state was calculated as (A+Z)/(A+V+Z), where V = violaxanthin, A = antheraxanthin, and Z = zeaxanthin.

Chlorophyll Fluorescence Parameters: Chlorophyll fluorescence was measured using a pulse-amplitude-modulated fluorometer. The maximum quantum yield of PSII (Fv/Fm), effective quantum yield (ΦPSII), non-photochemical quenching (NPQ), and electron transport rate (ETR) were determined according to standard protocols.

3.3 D1 Protein Analysis

The D1 protein content was determined by Western blotting using specific antibodies against the D1 protein. Thylakoid membranes were isolated from leaf samples, and protein concentration was quantified. Samples were loaded on an equal chlorophyll basis, separated by SDS-PAGE, and immunoblotted. The relative D1 protein content was normalized to control values.

3.4 ROS Content and Antioxidant Enzyme Activities

ROS Detection: Superoxide anion (O) and hydrogen peroxide (H O) contents were measured using colorimetric assays. Malondialdehyde (MDA) content was determined as an indicator of lipid peroxidation.

Antioxidant Enzyme Activities: Activities of SOD, APX, CAT, GR, and MDAR were assayed spectrophotometrically using established methods. Enzyme activities were expressed on a protein basis.

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4. Discussion and Conclusions

The photoinhibition defense mechanisms of *S. vulgaris* represent a complex, integrated system that enables this species to thrive in the harsh desert environment of Mu Us Sandland. The combination of energy dissipation through the xanthophyll cycle, D1 protein turnover, ROS scavenging, and photorespiration provides multiple layers of protection against light-induced damage. Understanding these mechanisms at the molecular and physiological levels is essential for elucidating how *S. vulgaris* adapts to its environment.

Future research should focus on the molecular regulation of these photoprotective mechanisms, including the expression patterns of key genes under different stress combinations and the signaling pathways that coordinate the various defense responses. Such studies will not only advance our understanding of plant stress physiology but also provide valuable insights for ecological restoration and vegetation management in arid and semi-arid regions.

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