

Engineering Photoreceptors for Future: The Unique Bodies Within Plants

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Photoreceptors are specialized proteins in plants that detect light and regulate growth and development. They have unique properties, such as light-absorbing pigments, and have evolved over millions of years to optimize plant functions in various light conditions. Photoreceptors impact processes like seed germination, stem elongation, and flowering, ensuring plants maximize light capture and productivity.



Engineering photoreceptors is crucial for sustainable agriculture, as it can enhance plant resilience to environmental stresses and improve crop yields. By modifying photoreceptors through genetic engineering, scientists aim to develop crops that are more efficient, resilient, and productive, addressing the challenges of climate change and food security.

What are photoreceptors?

Plant photoreceptors are proteins that capture light, initiating various light-dependent developmental and physiological processes. These receptors are vital for

detecting light across wavelengths from 280 nm (UV-B) to 750 nm (far-red light) and responding to light leading to significantly influencing plant growth, development, and survival. Key types include phytochromes, cryptochromes, phototropins, UVR8,

Zeitlupe (ZTL), FKF1, and LKP2.

Blue light, in particular, plays a crucial role in cell elongation, plant orientation, and flowering. Studies show that photoreceptor

activity affects various growth stages, including seed germination, plant structure, flowering, reproduction, biomass accumulation, and senescence.

Background and History

The study of plant responses to light began with observations of tropisms, such as phototropism, where plants grow towards light. In the late 19th century, Charles Darwin and his son Francis discovered that light is detected at the tip of the plant shoot and suggested a mobile signal directs growth, though they did not identify the photoreceptor. The identification of

phytochromes in the 1950s marked a significant advancement (Darwin & Darwin, 1880). The discovery of phytochromes was made by Sterling Hendricks and Harry Borthwick, who showed that red light could initiate germination in lettuce seeds, a process reversible by far-red light.

Subsequent discoveries included cryptochromes in the 1990s, which are blue light-sensitive photoreceptors crucial for regulating circadian rhythms and seedling development. Research on these photoreceptors was advanced using the model organism *Arabidopsis thaliana*. In the early 2000s, phototropins, another type of blue light receptor, were discovered. These photoreceptors mediate phototropism, chloroplast movement, and stomatal opening. Their identification involved genetic, molecular, and biochemical methods.

The most recent addition to the plant photoreceptor family is UVR8, which detects UV-B light. Discovered in the early 21st century, UVR8 has provided insights into how plants respond to UV radiation and protect themselves from damage.

Evolution and Types

Photoreceptors have evolved over millions of years, originating in early photosynthetic organisms where light perception provided an evolutionary advantage. As plants adapted to terrestrial environments, their photoreceptor systems became more complex, regulating processes like circadian rhythms and seasonal flowering (Rockwell *et al.*, 2006).

Advancements in molecular biology, genetics, and biochemistry have revealed the signaling pathways of photoreceptors. Techniques such as mutant analysis,

gene cloning, and protein crystallography have been crucial in understanding their structure and function.

Currently scientists explore the dynamics, diversity and complexity of photoreceptors, focusing on their roles in stress responses, light environment adaptation, and integration with other signaling pathways. This research provides insights into plant adaptation to terrestrial habitats and varying light conditions (Jiao *et al.*, 2007). Plant leaves absorb blue and red light for photosynthesis, reflecting far-red light, which alters light composition in shaded areas.

1. Phytochromes
2. Cryptochromes
3. Phototropins
4. UVR8

Role of Photoreceptors in Plants

Photoreceptors are crucial for plants as they enable the perception of light, which is essential for various growth and developmental processes. The primary photoreceptors in plants include phytochromes, cryptochromes, phototropins, and UVR8, each responding to different light wavelengths.

- 1. Phytochromes:** These are red and far-red light receptors that can exist in two interconvertible forms, Pr and Pfr, depending on the specific wavelength of light absorbed. These receptors play a crucial role in regulating a variety of developmental processes in plants, such as seed germination, shade avoidance responses, and the timing of flowering.
- 2. Cryptochromes:** These are primarily sensitive to blue light, are integral to regulating seedling development, photoperiodic flowering, and circadian rhythms in plants. It perceives blue light

which helps in hypocotyl elongation and amplifies the petiole elongation response mediated by low R:FR ratios in Arabidopsis.

- 3. Phototropins:** These are blue-light receptors that play a key role in mediating phototropism, which is the directional growth of plants toward light. They also regulate chloroplast movement and stomatal opening.
- 4. UVR8:** UVR8 is a specialized receptor that detects UV-B light, contributing to plant acclimation under

high light conditions. It plays a crucial role in DNA repair and the biosynthesis of protective compounds, such as flavonoids, which help mitigate UV-induced damage.

- 5. ZTL & FKF1:** Zeitlupe (ZTL) and Flavin-binding, Kelch repeat, F-box proteins (FKF1) are blue light-absorbing photoreceptors that are essential for regulating the circadian clock and photoperiodic flowering in plants.

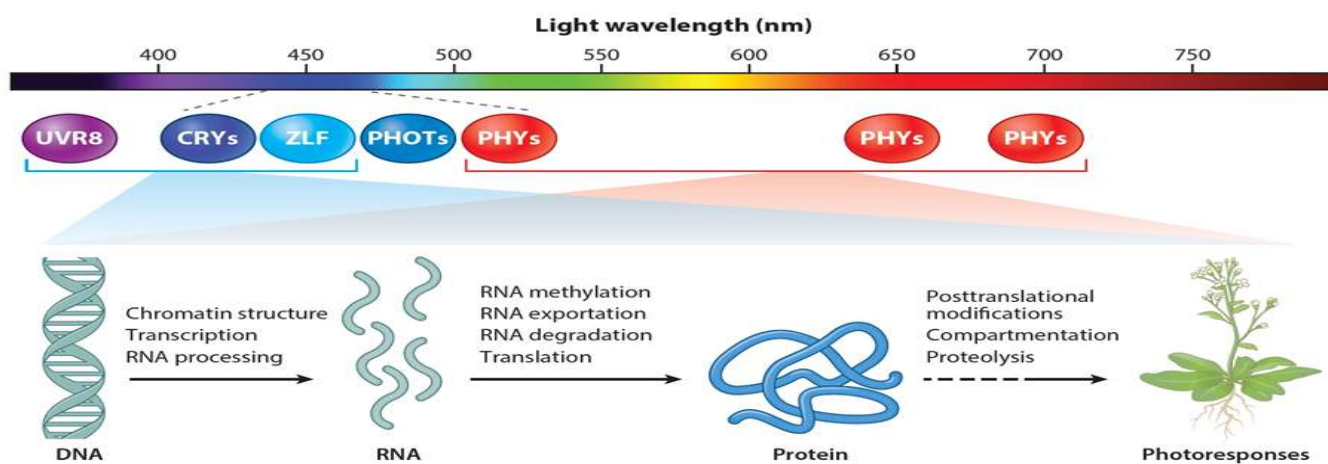


Fig.1. Photoreceptors in Plants

Impact on Plant Growth and Production

- 1. The influence of photoreceptors on plant growth and agricultural productivity is significant.** They regulate key developmental processes that affect yield and quality, such as:
- 2. Seed Germination:** Light signals through photoreceptors can trigger germination, ensuring seeds sprout at optimal times.
- 3. Biomass Production:** By regulating growth rates and patterns, photoreceptors influence overall biomass accumulation, which is vital for crop yields.

- 4. Flowering and Fruiting:** Photoreceptors determine flowering time and fruit development, impacting the quantity and quality of produce.
- 5. Stress Responses:** They also play a role in plant defense against pests and diseases, which is crucial for maintaining crop health and productivity under varying environmental conditions (Mawphlang & Kharshiing 2017).

Need for Photoreceptor Engineering in Plants

The engineering of photoreceptors in plants is becoming increasingly important due to the challenges posed by climate change, population growth, and food security. Key reasons for this need include:

1. **Adapting to Environmental Changes:** As climate conditions become more variable, engineered photoreceptors can help crops adapt to changing light conditions, ensuring stable growth and yield.
2. **Improving Crop Resilience:** Enhanced photoreceptor signaling can lead to better stress responses, allowing plants to thrive under adverse conditions, such as drought or nutrient deficiency.
3. **Maximizing Agricultural Productivity:** By fine-tuning photoreceptor functions through genome editing, it is possible to create crops with optimized growth patterns, leading to increased yields and improved quality of food products. Manipulating photoreceptor pathways can lead to increased biomass accumulation, which is crucial for improving crop yields. For example, overexpression of phytochrome A in tobacco suppressed shade avoidance, causing plants to allocate more assimilates to leaves and increasing harvest index at high densities.
4. **Sustainable Agriculture:** Engineering photoreceptors can contribute to sustainable farming practices by reducing the need for chemical inputs and enhancing natural plant defenses against pests and diseases (Ronald & Ballaré 2021).

Conclusion

Research indicates that manipulating photoreceptor pathways can lead to desirable agronomic traits, such as improved disease resistance, enhanced fruit quality, and optimized growth under different light conditions. These photoreceptors work through complex signaling pathways that integrate light signals with hormonal responses, particularly involving auxin, which regulates growth patterns and responses to environmental changes. In conclusion, photoreceptor engineering holds significant potential for advancing agricultural practices, ensuring food security, and promoting sustainable crop production in the face of global challenges.

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