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Genetics of Circadian Rhythm and Role in Plant Development

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Abstract

Organisms have evolved special types of sensors to sense light and temperature, enabling them to respond to environmental changes by maintaining homeostatic balance. Still, it is also beneficial to foresee the daily changes. Most organisms, including plants, have developed an internal timing mechanism known as the circadian clock that enables them to anticipate environmental changes.

Introduction

A circadian rhythm is a natural, internal process that mainly regulates the sleep-wake cycle and repeats every 24 hours. It can refer to any biological process that displays an endogenous, entrainable oscillation of about 24 hours. A circadian clock drives these 24-hour rhythms, which have been widely observed in plants, animals, fungi, and cyanobacteria. The term *circadian* is derived from the Latin word *circa*, meaning "around," and *diēm*, meaning "day." The study of temporal rhythms in biological systems during daily, tidal, weekly, seasonal, and annual rhythms, is called chronobiology. Processes with 24-hour oscillations are called diurnal rhythms; they should not be called circadian rhythms unless the rhythm is endogenous.

General criteria to be called circadian, a biological rhythm

- The rhythm has an endogenous free-running period that lasts approximately 24 hours. The rhythm persists in constant conditions (i.e., constant darkness) for about 24 hours. A rhythm can't be said as endogenous unless it has been tested and continues in conditions without external periodic input.
- The rhythms are entrainable. The rhythm can be setback by exposure to external stimuli (such as light and heat), a process called entrainment.

- The rhythms should be temperature compensation. In other words, they maintain circadian periodicity over physiological temperatures. Many organisms live at a broad range of temperatures, and differences in thermal energy will affect the kinetics of all molecular processes in their cell(s). To maintain time track, the organism's circadian clock must maintain roughly a 24-hour periodicity despite the changing kinetics. This is known as temperature compensation.

A basic model of the plant circadian system

Formally, the circadian system can be divided into three conceptual parts:

- Input pathways that entrain the clock
- Central oscillator (clock)
- Output pathways to generate overt rhythms

1) Input (Entrainment)

Circadian rhythms persist without external time cues but are entrainable to the environment. It has long been clear that clock response to environmental stimuli varies over the circadian cycle.

- **Light**: Although many environmental parameters provide stimulus to the clock, the most potent and best-characterized stimulus in plants is light period length is inversely related to light intensity in plants and animals that are active in the light. For example, in Arabidopsis, Phytochrome A(PHYA) and Phytochrome B(PHYB), as well as Cryptochrome 1(CRY1) and Cryptochrome (CRY2), contribute to the establishment of period length. PHYB is essential at high intensities of red light, whereas PHYA functions at low intensities. The expression of genes governing photoreceptors varies with varying light periods, which plays a crucial role in the circadian organization.
- **Temperature:** Although the circadian oscillator is temperature compensated, temperature pulses or temperature steps are potent entraining stimuli, thus helping the plants in adapting to the changes in varied environmental conditions. Circadian rhythm act as a buffering system in resisting fluctuations due to temperature.
- **Photoperiod:** The flowering time in many species is regulated by photoperiod, light quality, and vernalization. Photoperiodism makes use of day-length information to sense and prepare for seasonal variations. Circadian rhythm is a 24-hour internal cycle that plays a prominent role in maintaining the physiology of plants.

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2) **Central Oscillator (Clock)**

Genetic and molecular biological analyses in various systems suggest that the central oscillator is a negative feedback loop or, as emerging evidence from eukaryotic systems indicates, two interlocked feedback loops. Rhythmic transcription of crucial clock genes is inhibited by the nuclear (in eukaryotes) accumulation of the protein products of these genes. No clear picture has yet emerged, but it is apparent that many of the themes of other clock systems are conserved in plants.

3) **Rhythmic Outputs**

- **Movement and Growth Rhythms**: This mainly includes the pulvinar leaf movements, a classical system in which cells in the extensor and flexor regions of the pulvinus swell during antiphase (180◦ out of phase) to drive an oscillation motion in leaf position. For example, stems of inflorescences in Arabidopsis exhibit a circadian oscillation in elongation rate that is correlated with the amount of indole-3-acetic acid (IAA) in rosette leaves. However, IAA levels in the inflorescence stem do not oscillate.
- **Stomatal Aperture, Gas Exchange, and CO2 Assimilation:** Circadian rhythms in the stomatal aperture are well documented and are correlated with a circadian rearrangement of the guard cell cytoskeleton. In beans, there is circadian control of Calvin cycle reactions in addition to the management of stomatal aperture and gas exchange. Arabidopsis exhibits a circadian rhythm in the CO2 assimilation process. Circadian rhythms of CO2 assimilation in Crassulacean Acid Metabolism (CAM) have been well studied.
- **Hormone Production and Responsiveness**: Circadian rhythmicity is mainly involved in Ethylene production in several species. For example, sorghum rhythmicity helps in encoding the SbACO2 gene encoding 1-aminocyclopropane-1-carboxylic acid (ACC) oxidase enzyme, which is a critical enzyme in ethylene synthesis.
- **Rhythms in Gene Expression:** Genes are expressed rhythmically and are driven by the internal timing mechanism.

Circadian rhythm and plant growth

- Flowering: A systemic signal called florigen helps initiate flowering in plants and is then synthesized, transmitted from leaves to the shoot apical meristem through the phloem, and induces floral development.
- Hypocotyl elongation: Circadian clock regulates a daily, and rhythmic elongation of hypocotyls helps accelerate hypocotyle elongation.
- Movement and growth rhythm: Biological rhythms are very responsive to environmental cycles, while growth regulation contributes to rhythmic movement in plants.
- The circadian clock regulates the main physiological activities of plants, such as closing and opening stomata, gas exchange during respiration, and assimilation of carbon-di-oxide.
- Hormone production and responsiveness: Hormones are involved in many biological and physiological regulations and are highly regulated by the circadian and sleep-wake cycles.
- Cell senescence, which shows permanent arrest in growth and response to various stress conditions, is controlled by circadian rhythm.
- Circadian regulation of Plant defense system**:** Phytohormones such as jasmonates and salicylic acid mediates plant response during biotic and abiotic stresses. The accumulation pattern of phytohormones is internally clock-regulated.

Conclusion

Circadian rhythms are conserved throughout evolution that foresight day/night cycles and help optimize their physiological and behavioral changes in plants. Circadian rhythms regulate many developmental stages, from single-cell organisms to multicellular organisms. Understanding the molecular basis of circadian rhythm helps treat many diseases of crop plants; hence better crop improvement can be achieved.

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