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15. Photoperiodism and Vernalization

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Abstract:

The physiological to the duration of night or a dark period is known as photoperiodism or the developmental reactions of plants to the relative lengths of light and dark cycles is known as plant photoperiodism. Garner and Allard (1920) were the first to observe clearly that, depending on the plant, long days (LD) or short days (SD) could accelerate flowering and many other reactions in plants. A pair of identical protein molecules attached to separate light-absorbing molecules forms the homodimer known as phytochrome. Plants possessed five different types of phytochromes: PhyA, PhyB, C, D, and E. Vernalisation can be defined as chilling treatment applied to plant buds, seed or seedlings to induce early flowering. In addition to receiving proper light exposure, certain plants need to undergo a period of low temperatures during their early growth stages in order to bloom. John Hancock Klippart discovered the first evidence of vernalization in 1857 when he discovered that winter wheat. Vernalization induces early flowering, reduces the vegetative phase of plants, and increases yield.

Keywords:

Photoperiodism, Day length, Phytochrome, Vernalization, Flowering

15.1 Photoperiodism:

Plant photoperiodism refers to the developmental responses of plants to the relative lengths of light and dark cycles, while photoperiodism refers to the physiological response of an organism to the duration of night or a dark period. Numerous elements of plant growth are regulated by the photoperiod, which is the duration of the light period throughout a 24-hour period. Various wavelengths of the sun are sensed by photoreceptors, which subsequently utilized this for the circadian clock's core oscillator, composed of linked molecular gears that produce a 24-hour rhythm (Lin, 2000). Parts of the circadian clock are encoded by regulatory genes that are activated at specific periods, such as morning-phased genes at the beginning of the light cycle or evening-phased genes at the beginning of the dark period. To control how plants adapt to various light regimes, photoperiod in plants combines information from the circadian clock and perception of light. Therefore, to balance their ecological fitness, the ability of adult organisms to create offspring before they die—plants synchronize important developmental transitions with favorable conditions and adjust their growth in response to seasonal variations.

Distinct developmental transitions are regulated by distinct photoperiods. For example, in poplar trees, SDs promotes growth cessation in the autumn while LDs start vegetative growth in the spring. Known as the floral transition, this shift from the vegetative to the reproductive phase is an excellent illustration of how several photoperiods can regulate the same developmental process in distinct plants.

Certain plants that thrive in tropical climates favor short days, or even neutral days (12 hours of light and 12 hours of darkness), for the development of reproductive structures, while plants thriving in temperate regions prefer long flowering times. Consequently, photoperiod controls several developmental stages in the plant life cycle.

15.2 Discovery:

Henfrey postulated in 1852 that at least some of the natural distribution of plants may be explained by latitudinal variations in summer daylength (Henfrey, 1852). However, Kjellman conducted first studies where daily length of light was manipulated in the Arctic Circle (Naylor, 1961). Longer light periods accelerated plant development, although it was unclear whether the effects were photosynthetic or photoperiodic. Experiments to extend the daily light period were made possible by the introduction of the incandescent electric light in the latter part of the nineteenth century (Rane, 1894).

Numerous summer andals experienced an acceleration of flowering as a result of these electrohorticultural endeavors. Despite the relatively low illumination levels utilized in these tests, photosynthetic effects were not strictly ruled out, and the significance of the photoperiod was not acknowledged. Around the turn of the 20th century, Hans Klebs and Julien Tournois separately claimed that a key determinant in plant development is the length of light in the daily cycle, not the quantity (Tournois, 1912).

In his research, Tournois discovered that under glass, the SDP Humulus and Cannabis plants blossomed early in the winter. After ruling out the influence of temperature, humidity, and seed origin, he started his important daylength research in 1912. He discovered that although plants grew more slowly, they blossomed most quickly when exposed to just 6 hours of light every day. Around the same period, Klebs (1913) was doing meticulously monitored studies on *Sempervivum funkii*, an LDP, blossoming. By exposing the rosettes to constant light from incandescent lamps for a few days in the middle of winter, he was able to induce 10 flowers.

However, Garner and Allard (1920) were the first to observe clearly that, depending on the plant, long days (LD) or short days (SD) could accelerate flowering and many other reactions in plants. They categorized plants into the current photoperiodic groupings and coined the terms "photoperiod" and "photoperiodism." Their observations of two plant species that were being bred at the time guided their discoveries.

Regardless of the planting date, flowering tended to happen at the same time in some *Glycine max* types, especially the late maturing strain Biloxi (Table 15.1). Second, in the summertime in Washington, DC, the *Nicotiana tabacum* variety known as the Maryland Mammoth grew enormously outdoors but did not produce flowers. But in the winter and early spring, plants grown in pots behind glass blossomed while still relatively little. Garner and Allard expanded their observations to include a wide range of species and responses following their original research on flowering in *Nicotiana* and *Glycine*. They found that daylength affects a variety of plant behaviors, including as flowering, tuberization, and dormancy. They also thought about potential implications for plant spread and crop productivity.

15.3 Photoperiodic Response Group:

There appear to be three main types of reactions to daylength in terms of flower initiation, with some variants. They are a) Day-neutral plants (DNP), which flower regardless of photoperiodic conditions; b) Short-day plants (SDP), which only flower, or flower most rapidly, with less than a certain number of hours of light in each 24 h period; c) Long-day plants (LDP), which only flower, or flower most rapidly, with more than a certain number of hours of light in each 24 h period. Plants that react to day length can be further divided into obligate kinds, which require a given day length for blooming, and facultative (or quantitative) types, where a specific day length encourages flowering but is not necessary.

It can be difficult to distinguish between these two groups since certain circumstances may emphasize a photoperiodic requirement more than others. For example, a plant may have a mandatory photoperiodic need at one temperature but only show a facultative response at another. Perhaps it would be better to see these two reaction types as a continuum, where advantageous day lengths at one end of the spectrum somewhat accelerate flowering, while bad day lengths at the other end of the spectrum permanently delay flowering.

15.4 Assessment of Flowering Response:

Quantitative response measurement is necessary in order to examine how various interventions affect flowering. Numerous strategies have been employed. Even while they can all be helpful if used properly, several are subject to criticism. The results can be expressed in the simplest way possible, which could be the proportion of plants in each treatment that bloomed within a certain, arbitrary time frame. To assess the statistical validity of small variations, this necessitates the use of a large number of replicate plants, which is frequently not feasible in situations where space is limited. Because some ecotypes of *Chenopodium rubrum* are extremely photoperiodically sensitive, they may flower in a petri-dish, which makes it easy to grow a large number of them in a small area (Cumming, 1959).

A. What Is the Plant Actually Measuring?

It was discovered in 1940 that a crucial night length is absolutely necessary for photoperiodism to exist. According to the earliest published results of cocklebur trials, a cocklebur plant requires eight hours or more of continuous darkness every night in order to flower. This is the critical night length for the plant.

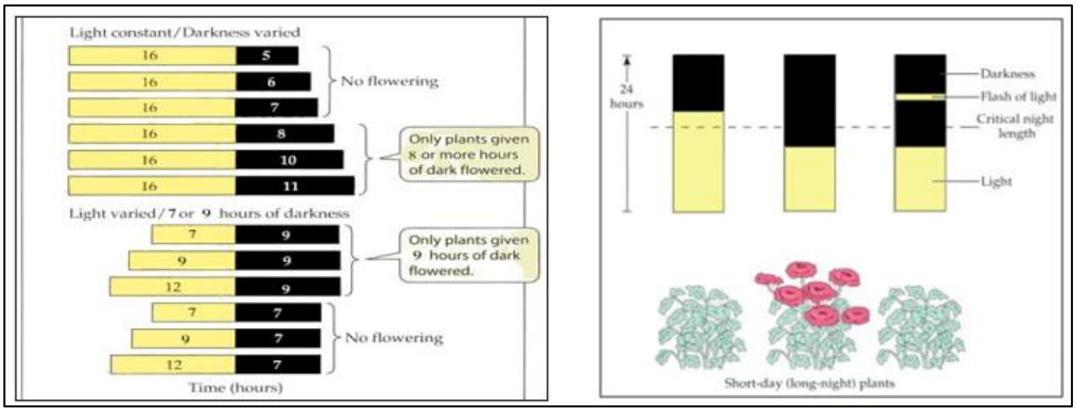

Figure: 15.1: Effect of Alternate Light and Dark Periods on Flowering in Cocklebur (From Campbell's Biology 5th Edition)

15.5 Various Models Regarding Photoperiodism and Flowering:

A. The Hourglass Model
B. Circadian Rhythm Model

15.5.1 The Hourglass Model:

According to the Hourglass model, a chemical product gradually accumulates within the organism. This chemical must be present in a specific amount to cause a physiological reaction. If the product is not degraded first, the threshold is met. It could only build up during the light phase and be destroyed by darkness, or it could build up during the dark period and be destroyed by light. When a threshold is reached—that is, when light (or dark) lasts long enough—a physiological reaction is triggered, like the maturity of the reproductive system. Because of the molecule's same behavior, Phytochrome was thought to be the culprit.

Phytochrome: A pair of identical protein molecules attached to separate light-absorbing molecules forms the homodimer known as phytochrome. Plants produce five different types of phytochromes: PhyA, PhyB, C, D, and E. While there appears to be some overlap in the functions of the several phytochromes, some seem to be specific to one or the other. Additionally, the phytochromes differ in their absorption spectra, or the wavelengths (such as red versus far-red) that they absorb most efficiently. There are two interconvertible types of phytochromes: PFR, which absorbs far-red (FR; 730 nm) light, and PR, which absorbs red (R; 660 nm) light.

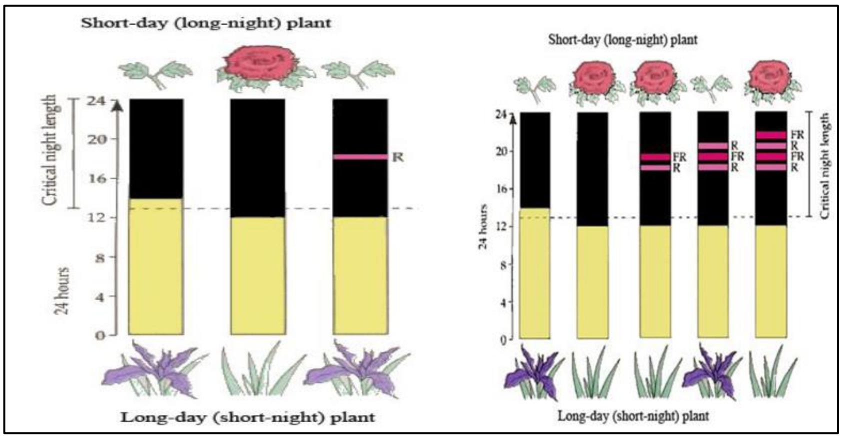

Figure 15.2: Effects Of Flashes of Red and Far-Red Light on Flowering in LDP And SDP (Campbell's *Biology, 5th Edition)*

15.5.2 The Circadian Rhythms:

These are biological activity rhythms that exhibit fluctuations over about a 24-hour period, even in the presence of constant ambient conditions (e.g., perpetual darkness). It is possible for the cycles to become out of sync with the surroundings under continuous settings. Nevertheless, the rhythms become entrained—that is, they now cycle in unison with the cycle of day and night for a period of precisely 24 hours—when exposed to the environment, such as alternating day and night. For the rhythms to synchronize, light must be detected by the 1. phytochromes, which absorb red light, and 2. cryptochromes, which absorb blue light.

Conclusion: Photoperiodism is the physiological reaction of plants to their sense of day length. (But in reality, the plant gauges the duration of the night.) These answers differ across SDP, LDP, and DNP. A molecularly regulated network of photoreceptors, transcription factors, Homeotic genes (ABC), and integrative genes (MADS-Box) is the main mechanism by which photoperiod influences flowering. In addition to the hourglass system controlled by phytochrome, the circadian mechanism, of which carbon dioxide is a major regulator, governs photoperiodic flowering. Day-length influences the expression of CO, which in turn modifies the expression of FT or SOC1 to cause blooming. In addition, it is thought that more Key regulators besides CO might be implicated in inducing flowering by internal coincidence.

15.6 Vernalization:

A plant's life cycle includes flowering as one of its most significant stages. To generate viable seeds and ensure the continued survival of the species in future generations, the time to flower must coincide with ideal conditions. A prolonged period of low temperature, known as vernalization, is one environmental trigger that ensures that flowering occurs in the appropriate season of the year, which is spring. Vernalization is necessary for the promotion of flowering in many plant species, including both grass-like plants (the monocots) and broadleaf plants (the dicots).

Vernalization is the chilling treatment applied to plant buds, seed or seedlings to induce early flowering. In addition to receiving proper light exposure, certain plants need to undergo a period of low temperatures during their early growth stages in order to bloom later on. Plants that need vernalization but do not receive the cold treatment experience delayed flowering or remain in a vegetative state. They are unable to respond to floral signals, such as specific light periods that induce flowering.

Winter annuals are sensitive to cold in the early stages of their life cycle, just like the winter varieties of grains, which are planted in the fall and flower the following summer. Actually, a lot of winter annuals can undergo vernalization prior to germination as long as the seeds have absorbed water and become metabolically active. The optimal temperature range for vernalization is usually between 1 and 7°C, with the most effective range being slightly below freezing to about 10°C.

A. History:

American agriculturist John Hancock Klippart discovered the first evidence of vernalization in 1857 when he discovered that winter wheat, which is sown in the winter and flowers in the summer, could be transformed into spring wheat, which is sown in the spring and flowers in the summer, provided the seeds were kept at a temperature close to freezing (0°–5°C) after a slight germination.

The term "jarovization" was coined by Soviet agronomist Trofim Lysenko in 1928 to refer to a method of chilling that he used to cause the seeds of winter cereals to behave like spring cereals (the word "jarovoe" in Russian originally meant "fire" or "the god of spring"). The word was translated as "vernalization" by Lysenko himself.

B. Detection of a Cold Stimulus and The Presence of a Floral Hormone:

The apical meristems detect the cold stimulus, leading to the production of a floral hormone that is then transported to other areas of the plant. In rare cases, a graft union may even allow the cold stimulus to spread to a different plant.

For instance, an unvernalized henbane plant will likewise begin to flower when it is grafted onto a vernalized henbane plant. This effect is attributed to the plant being stimulated to produce a hormone called Vernalin, as identified by Melchers in 1939.

C. Molecular Basis of Vernalization:

The most information regarding cold-induced blooming has been gathered for Cereals and Arabidopsis. In *Arabidopsis thaliana*, the MADS-box gene FLOWERING LOCUS C (FLC) primarily mediates the response to vernalization.

FLC is a repressor that inhibits floral activator expression, delaying flowering. Treatment with vernalization releases the promotion of flowering while suppressing FLC. Research indicates that FLOWERING LOCUS T (FT) and SUPPRESSOR OF OVEREXPRESSION OF CONSTANS 1 (SOC1) are the primary targets of FLC in Arabidopsis.

Flowering promotion in Arabidopsis is repressed before vernalization by the MADS-box transcription factor FLC, which interacts with the promoter region of the SOC1 gene and the first intron of the FT gene. FLC inhibits FT expression in the leaves while SOC1 is downregulated in the shoot apex. The FRIGIDA (FRI) gene upregulates FLC expression by means of a FRI-containing supercomplex, which creates a local chromosomal environment conducive to high-level FLC mRNA production.

Multiple factors contribute to the epigenetic silencing of FLC resulting from the vernalization treatment. Among these are:

- The autonomous pathway's constituent parts,
- The FLC locus (COOLAIR complex) produced long noncoding RNAs (lncRNAs),
- Poly-comb Repressive Complex 2 (PRC2), which is made up of the fundamental elements SWINGER (SWN), MULTICOPY SUPPRESSOR OF IRA1 (MSI1), FERTILIZATION INDEPENDENT ENDOSPERM (FIE), and VERNALIZATION 2 (VRN2).
- The plant homeodomain (PHD) proteins VIN3-LIKE2, VERNALIZATION 5 (VRN5), and VERNALIZATION INSENSITIVE 3 (VIN3).

The FT gene encodes a mobile flowering signal called "florigen" that stimulates the development of flowers. Florigen moves from the leaf to the apex through the phloem.

D. Interplay Between Vernalization and Photoperiod Pathways in Plant Flowering Control:

One way that the dicot and monocot systems are similar is that they both use the vernalization response in conjunction with the other environmental cue of longer days. The longer spring days cause the FT gene to become transcriptionally active in both kinds of plants. The systems that allow the FT gene to react are distinct, but they both lessen FT's repression. Long days are tolerated by FT in Arabidopsis due to the lack of FLC activity, and cereals lack VRN2 activity. In Arabidopsis, FT may respond to extended days when FLC activity is absent, and in cereals, FT can be induced by extended days when VRN2 activity is absent. The FT protein is transported from the leaves to the developing apex in both cereals and Arabidopsis, where it engages in genetic interactions to trigger the development of flowers. This activation of the FT response occurs in leaf tissue in both situations.

15.7 Conclusion:

The process of vernalization holds significant importance in the life cycle of plants, particularly those in temperate climates. It entails exposing plants to extended periods of low winter temperatures, which is essential for initiating or accelerating the flowering process. This mechanism ensures that crucial reproductive development and seed production occur in the spring and winters, as opposed to the autumn. Vernalization induces early flowering, reduces the vegetative phase of plants, and increases yield. It also provides resistance to cold and diseases, enabling biennial plants to grow and germinate at the appropriate time in their second year of life. Moreover, the principal regulators of the physiological mechanisms of blooming in flowering plants are photoperiodism and vernalization. Research into vernalization continues to advance our understanding, but it remains a complex phenomenon. Even though a lot has been accomplished, especially in the field of agriculture, there is still much to learn about the complexities of vernalization-induced flowering.

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