Chapter 15

Photosynthetic Adjustment to Temperature

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Summary

The description of a general mechanism for photosynthetic adjustment to temperature that encompasses all autotrophic species is not possible for three principal reasons: (i) inherent genetic diversity, (ii) differential strategies in growth and development, and (iii) organisms respond to temperature changes rather than to absolute temperature. Thus, ‘high’ and ‘low’ temperature are relative terms and will differ for psychrophilic, mesophilic and thermophilic organisms. However, given this complexity, some consensus regarding photosynthetic adjustment to temperature is emerging. At low temperature (0–10 °C), photosynthesis is constrained thermodynamically. This may be manifested by chloroplast phosphate limitation due to reduced rates of sucrose synthesis and/or source-sink limitations. In this case, rates of CO₂ uptake and O₂ evolution are regulated directly through metabolite accumulation (feedback inhibition) and photosynthetic control. Alternatively, feedback inhibition may be regulated indirectly through catabolite repression of photosynthetic genes. Although light may exacerbate susceptibility to photoinhibition at low temperature in many species, cold grown, chilling-tolerant plants exhibit increased capacity for carbohydrate synthesis at low temperature which alleviates phosphate limitation, supplies a cryoprotectant and results in higher photosynthetic capacity than warm-grown plants. However, photosynthetic adjustment in cold-grown higher plants and algae does not reflect adjustment to low temperature per se, but rather, changes in excitation pressure on PS II. In contrast, photosynthesis in chilling-sensitive plants is not only constrained thermodynamically by low temperature but is also severely inhibited developmentally.

Through a comprehensive molecular genetic study, a direct link between photosynthetic temperature acclimation and thylakoid lipid unsaturation has been established in cyanobacteria. However, the evidence for
such a link in algae and higher plants is still equivocal. PS I may be primary site for photoinhibition at low temperatures in some chilling-sensitive species. Furthermore, susceptibility to low temperature photoinhibition is reduced by altering the level of unsaturation of chloroplast lipids in chilling-sensitive transgenic tobacco plants.

With respect to high temperature (35–50 °C), the consensus is that thylakoid membrane stability limits photosynthetic performance. In contrast to low temperature, light protects against high temperature inhibition of photosynthesis.

I. Introduction

Land plants can experience and, thus, must be able to adjust to wide daily and seasonal fluctuations in temperature. In contrast, aquatic plants generally experience a more constant daily and seasonal temperature regime. The most productive marine environments are the Arctic Ocean and waters contiguous with the Antarctic continent where algae experience an average temperature of about –1.8 °C (Greene et al., 1992). When the external environment changes, responses by the plant to these changes may be separated into two principal components (Berry and Björkman, 1980; Prosser, 1986; Davison, 1991).

First, adaptation is a genotypic response to long-term changes. These alterations are stable and will remain in the population over generations. Second, acclimation, is a response induced by an environmental change which causes a phenotypic alteration over a single generation time without any corresponding compositional change in the genetic complement. However, acclimative responses can be differentiated further into: (i) transient physiological and biochemical adjustments induced by abrupt or short-term changes in the environment, that is, a stress response which subsequently may lead to damage and ultimately senescence, and (ii) stable, long-term adjustments which may reflect a developmental response to a new environmental condition. This response will prevail only as long as the new environmental condition persists. Frequently, it is difficult to distinguish between stress responses and developmental responses, especially since the stress response may be part of an adjustment leading to the developmental response. Regardless, the extent to which a plant can acclimate is ultimately under genetic control and the degree of plant plasticity will, in turn, be dependent upon the regulation and expression of many genes.

Photosynthesis represents an integration of photochemical as well as biochemical processes. Thus, ambient temperature fluctuations will have a direct impact on photosynthesis through its effects on the thermally sensitive biochemical and physiological processes. These include: (i) photosynthetic carbon reduction, (ii) sucrose synthesis, (iii) carbon partitioning, (iv) intersystem electron transport which is thought to be diffusion limited at the level of the mobile electron transport carriers, plastoquinone and plastocyanin (Lawlor, 1987). However, the photochemical events of light absorption, energy transfer and charge separation associated with PS II and PS I are insensitive to temperature in the biologically relevant range of 0 °C to 50 °C (Mathis and Rutherford, 1987). The combined effects of light and the differential sensitivity to temperature exhibited by the photochemical and thermochemical processes of photosynthesis can lead to metabolic imbalances which, in turn, can result in a significant impairment of photosynthesis as a result of photoinhibition (Powles, 1984).

In this chapter, we provide a general overview of recent advances regarding the effects of short- and long-term exposure to low or high temperature on