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Letter to Editor Open Access

The Difficult-to-Quantify Cyclic Electron Flux around Photosystem I in Leaves of Flowering Plants

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Letter to Editor

In oxygenic photosynthesis, two photosystems (PS II and PS I), using light, work in series to extract electrons from water to generate reducing power (in the form of NADPH) in linear electron transport, while the energy of the protons after water photo-oxidation is conserved in the form of ATP. Additionally, a cyclic electron flux (CEF) around PS I is also coupled to the formation of ATP [1]. Together, NADPH and ATP drive the conversion of CO2 into carbohydrates. CEF is central to the regulation of photosynthesis [2], but its quantification, six decades after the discovery, has been difficult because of the absence of net formation of a product or consumption of a reactant [3].

An indirect method has been used whereby the steady-state total electron flux through PS I (ETR1) and the linear electron flux through both photosystems (LEF) are determined, with both measurements made in the same leaf tissue under identical conditions. The difference (ΔFlux = ETR1 − LEF) is an upper estimate of CEF because ETR1 in general includes other partial electron fluxes through PS I. ΔFlux in greenhouse-grown spinach leaves increases with irradiance, and does not reach a maximum even when LEF is light-saturated [4]. At full-sun irradiance, CEF is almost as large as LEF. Measured at half of full-sun irradiance, about 90% of ΔFlux is inhibited by antimycin A, which inhibits ferredoxin-dependent plastoquinone reduction (FQR), a segment of the CEF pathway. Therefore, about 90% of ΔFlux appears to be CEF in greenhouse-grown spinach.

In Arabidopsis plants grown in low light, the situation is more complicated. Measured in low light equivalent to, or slightly above, the growth irradiance, ΔFlux was at least 50% as large as LEF in wild type leaves, and was completely inhibited by antimycin A, so ΔFlux ≈ CEF. In two mutants, one lacking FQR activity and the other lacking a minor regulatory (NDH) cyclic pathway, ΔFlux was <10% of LEF at such irradiances. On the other hand, at high irradiance, a large ΔFlux remained in the wild type (+antimycin A) and in the mutants, attributable to a partial forward electron flux that returned to the donor side of PS I (back reaction) in a kind of internal cycle in PS I [5].

When flowering plants with the C3 mode of photosynthesis are not exposed to excess light that promotes significant back reactions, the magnitude of CEF can be reasonably estimated. However, in cyanobacteria or leaves with the C4 mode of photosynthesis, in which the NDH-dependent cyclic pathway is much more prominent than the FQR-dependent cyclic pathway, it is much harder to estimate CEF. Further, non-flowering plants may have additional partial electron fluxes through PS I (or exiting before PS I) which make the quantification of CEF even harder.

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