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The structure and flexibility of the photosynthetic machinery in plants and algal cells

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In order to increase the efficiency of light capturing, all photosynthetic organisms capable of oxygen evolution have evolved multilamellar membrane systems of the thylakoid membranes, flat closed bilayer lipid vesicles, which accommodate the densely packed protein complexes in ordered, often semi-crystalline arrays. This highly organized system with substantial stability exhibit remarkable structural and functional flexibility at different levels of complexity, which enables these organisms to carry out rapid adaptations in response to changes in the environmental conditions. In this talk, my attention will be focused on the macro-organization of the protein complexes - and their role in determining the multilamellar membrane ultrastructure, and will show mechanisms that allow well identifiable reversible reorganizations in the internal order of the complexes and in the membrane system.

We have shown that the main chlorophyll a/b light harvesting complexes of photosystem II (LHCII) form chirally organized macrodomains both in vivo and in vitro. These macrodomains, together with stacking, play important roles in the lateral segregation (sorting) of the two photosystems between the granum and stroma membranes, and thus in the assembly and stabilization of the membrane ultrastructure [Mustárdy and Garab, 2003, TIPS 8: 117], which has been determined by electron tomography [Mustárdy et al., 2008, Plant Cell 20: 2552]. The macrodomains also possess a remarkable structural flexibility, being capable of undergoing light-induced reversible reorganizations, that are largely independent of the photochemical activity of thylakoids, and are approximately linearly proportional to the light intensity above the saturation of photosynthesis – an important, unique feature with respect to protection of plants against excess excitation [Barzda et al., 1996, Biochemistry 35: 8981]. This type of reorganizations include (i) unstacking of membranes, (ii) a lateral desorganization of the macrodomains, and (iii) monomerization of the LHCII trimers [Dobrikova et al., 2003, Biochemistry 42: 112726]. Isolated, lipid-enriched, loosely stacked lamellar aggregates of LHCII also possess the ability to undergo similar reorganizations, accompanied by fluorescence quenching transients. These structural transitions are accounted for by a biological thermo-optic mechanism: fast thermal transients, arising from dissipated excitation energy, which can lead to elementary structural transitions in the close vicinity of the site of dissipation due to the presence of 'built-in' thermal structure-instabilities [Cseh et al., 2005, Photosynth Res 86: 263]. They lend local structural flexibility to molecular (macro)assemblies of high stability, and appear to be involved in important enzymatic reactions, as revealed in other laboratories [Zer et al., 1999, PNAS 96: 8277, Yang et al., 2000, FEBS Lett 466: 385]. The lipid content of the membranes is self regulated by non-bilayer lipids, via their segregation capability. By this means they safe-guard the high protein content of the thylakoid membranes and, at the same time, they contribute to the structural flexibility of the membrane system [Garab et al., 2000 Trends Plant Sci. 5:489; Krumova et al., 2008, Biochim. Biophys. Acta, Biomembranes 1778: 997].

In order to characterize the multilamellar membrane system, we determined characteristic repeat distances of the photosynthetic membranes in living cyanobacterial and eukaryotic algal cells and in intact thylakoid membranes isolated from higher plants with time-resolved small-angle neutron scattering (SANS). It has been shown how the different organization of multilamellar membrane system can be correlated with different compositions and protein macro-organizations in different organisms. SANS also revealed small (˜10 Å) but well identifiable light-induced reversible changes in these organisms, observed for the first time in living cyanobacteria and diatom cells. These reorganizations, which could be recorded with time resolutions of several seconds and minutes, appear to be associated with functional changes in vivo [Nagy et al., 2011, Biochem J. 436: 225].

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