Carotenoids in Photosynthesis

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Carotenoids are essential for the survival of photosynthetic organisms [1-6]. They act as protective devices against irreversible photodestruction of the photosynthetic apparatus either by quenching chlorophyll (Chl) triplet states which prevents the Chl-sensitized formation of singlet state oxygen, a major oxidizing agent of Chl [7-9], by scavenging singlet oxygen directly [10,11], or by dissipating excess excitation energy beyond that which is required for photosynthesis [12-15]. Besides acting as photoprotectors of the photosynthetic apparatus, carotenoids function in several other capacities: (1) As light-harvesting pigments supplementing the light capturing ability of Chl in regions of the visible spectrum where Chl is not a very efficient absorber [16-20]. Carotenoids then transfer this energy to Chl and ultimately the excitation is trapped in the reaction center (RC) pigment-protein complex where it initiates a sequence of electron transfer events [21,22]; (2) As stabilizers of protein structure and facilitators of assembly of pigment-protein complexes [23-25]; (3) As regulators of energy flow - the mechanism by which this occurs is not yet fully understood, but it may involve energy transfer [26,27], electron transfer [15,28], or some other process that exerts control over the population of Chl excited singlet states [12,25,29-42]. (4) As redox cofactors [43] - investigations have shown that carotenoids function as electron donors in various pigment-protein complexes [44-48].

Considerable progress has been made in recent years in determining the structures of carotenoids in pigment-protein complexes. This has come about due to significant improvements in the procedures for the isolation, purification and biochemical characterization of the proteins, and to advances in the techniques for the crystallization and X-ray diffraction analysis of carotenoid-containing RC and antenna pigment-protein complexes. Studies on several purple photosynthetic bacteria [49-70], cyanobacteria [71-75], and algal systems [76] have located the protein-bound carotenoid molecules relative to the (bacterio)chlorophyll ((B)Chl) pigments. Light-harvesting complexes that have been investigated include LH1 [67] and LH2 [60] from photosynthetic bacteria, LHCII from higher plants [75,77] and the peridinin-Chl-protein (PCP) complex from the dinoflagellate, Amphidinium carterae [76]. In addition, Xray crystallographic investigations of Photosystems I (PSI) and II (PSII) have established the structures of some core antenna proteins associated with these RCs [72-74]. Yet, the structural aspects of carotenoids important in controlling their function still have not been clarified. This is because the complexes whose structures have been determined are very diverse and display many different structural motifs making it difficult to draw any generalizations regarding the function of carotenoids in these complexes. The reasons for the variability in efficiency are largely unknown, but depend on factors such as the conformation of the carotenoid, the nature and position of its excited states relative to (B)Chl, the orientation of the carotenoid with respect to (B)Chl, the distance between the carotenoid and (B)Chl, spectral overlap, and the dynamics of the participating states [60,65,78]. Several more studies will be needed before any general relationships between the carotenoid structures and biological functions emerge, and this is a major focus of activity by scores of research groups around the world. It is also hoped that lessons learned from studies on photosynthetic organisms will aid in the design of new and improved devices for efficiently harvesting and converting solar energy into electrical and chemical potential for powering our planet.

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