IN BRIEF

Orange Carotenoid Protein Quenches Excess Energy and Singlet Oxygen

Harnessing light for energy gives photosynthetic organisms free energy—great, right? Well, like so many free things, too much of a good thing can turn into a bad thing, like a drought-ending rain that turns into a levy-breaching flood. The photosynthetic apparatus, beautifully adapted to capture light, can incur serious damage when too much light energy floods in. Given the variability of light conditions in the environment, photosynthetic organisms have, by necessity, adapted to manage excess light. For example, in cyanobacteria, blue light causes a conformational switch of the Orange Carotenoid Protein (OCP) from its dark-stable, orange form (OCP<sup>o</sup>) to its light-activated, red form (OCP<sup>r</sup>) via absorption by OCP’s associated carotenoid, 3′-hydroxyechinenone (reviewed in Kirilovsky and Kerfeld, 2013). OCP<sup>r</sup> binds to the light-harvesting phycobilisome complex, where it quenches excess energy, diverting energy away from the photosystems and dispersing it as heat. The unstable OCP<sup>r</sup> readily reverts to OCP<sup>o</sup>; therefore, OCP<sup>r</sup> only acts as a floodgate for excess energy under high-light conditions.

Blue-green light activates the energy quenching activity of OCP, but red-orange light does not. However, Sedoud et al. (pages 1781–1791) showed that OCP has an additional activity in photoprotection, as it protects Synechocystis cells from photodamage by red light (see figure): Cells lacking OCP show stronger inhibition of photosystem II activity caused by strong red light. Activity of photosystem II (PSII) in Synechocystis cells illuminated with strong red light for the indicated times. Synechocystis genotypes: wild type (WT), cells lacking OCP (ΔOCP), photodamage-sensitized cells (ΔpsbA2), and cells overexpressing OCP in the ΔpsbA2 background (OE-OCP). (Reprinted from Sedoud et al. [2014], Figure 1.)

OCP protects Synechocystis cells from photodamage caused by strong red light. Activity of photosystem II (PSII) in Synechocystis cells illuminated with strong red light for the indicated times. Synechocystis genotypes: wild type (WT), cells lacking OCP (ΔOCP), photodamage-sensitized cells (ΔpsbA2), and cells overexpressing OCP in the ΔpsbA2 background (OE-OCP). (Reprinted from Sedoud et al. [2014], Figure 1.)

The authors hypothesized that this effect might involve singlet oxygen, 1^O_2. In addition to inundating the photosynthetic apparatus with excess energy, excess light energy arriving at the reaction centers can induce the accumulation of singlet oxygen 1^O_2 via charge recombination reactions and chlorophyll triplet formation (reviewed in Fischer et al., 2013). Indeed, the authors used histidine-mediated chemical trapping to show that OCP decreased 1^O_2 production in intact Synechocystis cells (figure). Moreover, the authors found that OCP isolated from different Synechocystis strains could quench 1^O_2 production in response to the photosynthesisers methylene blue and Rose Bengal. The different strains used to isolate OCP differed in carotenoid composition, indicating that the OCP protein structure affects 1^O_2 quenching more than the associated carotenoid. OCP quenches 1^O_2 by physical means (whereby the carotenoid gains energy from 1^O_2 and then returns to the ground state) and by chemical means (whereby 1^O_2 oxidizes the carotenoid). However, not all carotenoid binding proteins can quench 1^O_2; the authors found that Red Carotenoid Protein from Anabaena did not quench 1^O_2, despite its similarity to the N-terminal domain of OCP.

The presence of singlet oxygen indicates a serious situation for the cell, the first trickles of impending disaster, and singlet oxygen also functions as a key signaling molecule to trigger high-light responses, including transcriptional and translational changes that result in acclimation or programmed cell death. However, the pathway by which such a short-lived molecule, with a microsecond half-life, functions in long-distance signaling remains unclear. This identification of OCP’s function in quenching singlet oxygen provides new information on the fate of 1^O_2 in the cell and reveals another mechanism by which cells protect themselves from the flood of light.

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REFERENCES


