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Editorial: Environmental Stress-Promoting Responses in Algae

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Editorial on the Research Topic

Environmental Stress-Promoting Responses in Algae

Algae live in the hydrosphere, where they experience fluctuations in temperature, salinity, nutrient levels, and sunlight, as well as other environmental stresses (Kumar et al., 2014; Raven and Giordano, 2014). The various responses involved in stress tolerance allow the algae to acclimate to these diverse environmental stresses (Flores–Molina et al., 2014; Kishimoto et al., 2019; Omuro et al., 2021). For example, algae vary their growth and reproduction under stress conditions as a tolerance mechanism to help survive disadvantageous conditions (Helmuth and Hofmann, 2001; Eckersley and Scrosati, 2012; Nayaka et al., 2017). Changes in gene expression also have essential functions in adaptive responses to stress. Moreover, each environmental stress promotes the expression of cognate sets of genes; therefore, stress responses can be recognized based on global changes in the stress-inducible accumulation of newly synthesized proteins and metabolites (Collén et al., 2007; Dittami et al., 2009; Cao et al., 2017; Sun et al., 2019; Rugiu et al., 2020). However, in contrast to the well-studied stress responses of land plants, little is known about the mechanisms regulating these physiological responses and the functions of the accumulated proteins and metabolites in algae. To address this knowledge gap, it is necessary to explore the physiological and molecular mechanisms of the stress-dependent regulation of growth, morphogenesis, gene expression, and metabolite biosynthesis in algae and how they affect biological, molecular, and biochemical levels. The resulting information will help us understand the responses of algae to environmental stress, which might distinct in part from those in land plants. Indeed, current studies on stress responses in streptophyte algae represented the differences in functions of conserved components of stress signaling networks between land plants and algae (Fürst-Jansen et al., 2020).

This Research Topic aims to establish an integrated view of how micro- and macro-algae regulate the physiological events involved in stress acclimation. Various aspects of the physiological responses of algae to environmental stress are reviewed, such as reproduction, growth, energy metabolism, and microbe-dependent responses in macroalgae, and gene expression, photosynthesis, and metabolite accumulation in microalgae. Recent physiological studies have indicated that abiotic stresses promote the transition from growth to the sexual and asexual reproductive phases (Liu et al., 2017). Suda and Mikami obtained novel findings about the effects of wounding and heat stress on the reproduction of thalli of the red alga *Pyropia yezoensis* (recently re-classified as *Neopyropia yezoensis*). In these algae, wounding promotes sexual and asexual reproduction, and heat stress induces callus production as a form of asexual reproduction. These findings demonstrate that the gametophytic thalli of *P. yezoensis* respond to environmental stress by resetting the timing of reproduction, in a phenomenon known as the life cycle trade-off (Liu et al., 2017).

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Algae commonly experience changes in salinity (Kirst, 1989; Karsten, 2012; Kumar et al., 2014). To explore responses to this common stress, Wen et al. performed a data-independent acquisition quantitative proteomic analysis of salinity-stressed *Pyropia haitanensis*. The abundances of proteins associated with the glycolytic pathway, the tricarboxylic acid cycle, and the pentose phosphate pathway varied under hypersaline conditions, indicating that salinity stress alters energy metabolism in *P. haitanensis*. Identifying protein biomarkers for salinity stress provided new knowledge that may enable efforts to develop salt-tolerant seaweed cultivars. In addition, Endo et al. investigated the accumulation of nitrogen in meristems of the brown alga *Eisenia bicyclis*, showing that the breakdown of blades due to heat stress promoted nitrogen accumulation in meristems in the lower part of the blade, which in turn promoted the intercalary growth of the algae. Moreover, Xu et al. demonstrated that the coccolithophore *Emiliania huxleyi* acclimates to low-salinity stress by upregulating photosynthetic performance under conditions that replicate ocean acidification. These findings suggest that macro- and micro-algae have a variety of stress-dependent mechanisms to tolerate the negative impacts of environmental stresses.

Various types of environmental stress cause cellular damage in photosynthetic organisms via the production of reactive oxygen species (ROS) such as superoxide anion (O_2^-) and hydrogen peroxide (H_2O_2) (Kumar et al., 2014; Choudhury et al., 2017; Hasanuzzaman et al., 2020). These algae have evolved ROS-scavenging systems to adapt to these stresses and protect their photosynthetic machinery (Mittler et al., 2011; Hasanuzzaman et al., 2020). Using a reverse-genetics approach, Lee et al. determined that the early light–inducible protein ELIP3 protects the green microalga *Chlamydomonas reinhardtii* from high-light- and cold-induced photooxidative damage to the photosynthetic machinery and enhances survival of these algae. In addition, Kumari et al. revealed that volatile organic compounds (specifically long-chain fatty aldehydes and fatty alcohols) function as chemical messengers to scavenge ROS in the arachidonic acid–accumulating microalga *Lobosphaera incisa* under nitrogen-deficient conditions. Finally, Singh et al. uncovered the roles of tocopherols as antioxidant molecules in the Selenastraceae algae *Monoraphidium* sp. under low-nutrient conditions. These findings highlight the critical roles of ROS scavenging in environmental stress responses in algae.

Microbe–seaweed interactions are critical for regulating algal development, as some algae acquire morphogenesis-promoting factors from bacteria (Egan et al., 2013; Singh and Reddy, 2014; Wichard et al., 2015). Ghaderiardakani et al. described an additional important aspect of this interaction: the involvement of microbes in the growth and development of healthy algae under various environmental stress conditions. These findings provide new insight into the survival of algae under stress conditions in the hydrosphere.

In conclusion, this Research Topic highlights novel findings that significantly increase our understanding of how stress-inducible responses operate and their effects on gene expression, the production of functional molecules, reproduction, and survival in algae.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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