Crop photosynthesis for the twenty-first century

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Energy from the sun supports all life on our planet. This life-giving energy is transformed by the photosynthetic process in plants into forms of energy that can be used by other organisms. Humans, through crops, can obtain all essential substances necessary for life. We depend on plant life, photosynthesis, and the complex chain of metabolic reactions; however, the photosynthetic process converts only approximately 5% of the energy that plants receive into biomass (Zhu et al. 2008). For decades, we have been trying to understand how photosynthetic organisms work, how they adapt to changes in the environment, and how plant photosynthesis controls crop yields.

However, evidence from recent decades has also shown that the Earth's human population and economic growth contribute to the intensification of the greenhouse effect and global warming. As a result, agricultural and surrounding ecosystems will be affected. The consequences will range from disruption of ecosystem services and loss of biodiversity to a decline in crop production and quality at a regional level. Additionally, climate extremes; drought, high temperatures, and increases in salinity, etc. are factors that are clearly damaging plants and leading to consequences in terms of food insecurity.

The twentieth century was a period of economic growth, as well as a period of intense study of plant mechanisms and of the development of methodology in plant research (Nagy and Garab 2021), which has improved the performance of cultivated species and, consequently, increased

food production. As part of the green revolution, plant scientists primarily use conventional techniques to improve yields, for instance, producing plants with shorter stalks and increased seed production (Srinivasan et al. 2017; Adamidis et al. 2019; Simkin et al. 2019; Yan et al. 2021).

The sustainability of crop production and the implications of the latest scientific knowledge on plant regulatory mechanisms must also be among the most important targets for innovation in photosynthesis research (Allakhverdiev 2020a,b; Ritchie et al. 2021). Additionally, along with climate change challenges, the problem of arable land shortages has also arisen. Clearing new lands for crop production may have a negative impact on unique environments, and the use of low-quality land requires additional approaches to obtain the required yields. Therefore, crop yields must be improved without increasing the amount of cultivatable land.

Taking into consideration that a given plant variety will perform differently according to geography and season, studies of genetic changes may significantly contribute to plant performance and crop improvement. The discovery of dwarfing genes delivered a principal genetic source for the development of high-yielding varieties of wheat and rice worldwide. In *Arabidopsis thaliana*, tobacco, and tomato, the overexpression of sedoheptulose-1,7-bisphosphatase results in an increase in both photosynthetic carbon assimilation and biomass yield. As another approach to increase crop productivity, cyanobacterial enzymes are expressed in higher plants, causing an enhanced rate of growth and photosynthetic CO₂ fixation (Miyagawa et al. 2001; Ding et al. 2016; Simkin et al. 2019; Chen et al. 2021).

Measurements of photosynthetic parameters have become the basis for research on genetic resources, the breeding of modern varieties, and the improvement of technological processes in the cultivation of crops worldwide.

Photosynthesis is the primary determinant of crop yield, but plants absorb more solar light than they can effectively use. There are suggested options to improve the photosynthetic machinery of plants by inserting the machinery from a purple photosynthetic bacterium and by the replacement of chlorophyll *a* with chlorophyll *d* from the cyanobacterium

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Acaryochloris marina. Thus, biotechnology can be a powerful tool for redesigning the production of crop plants with higher yields, which can bring humanity closer to solving future agricultural crises.

The development of science is not uniform; it depends not only on leaps in knowledge in related disciplines but also on the accumulation of information. It is therefore important that the topic of photosynthesis and production be addressed worldwide so that scientific knowledge is transferred to farmers and breeders, especially in countries with large population growth.

Over the past decades, the global demand for crops for food and fuel production has significantly increased to try to keep pace with the growing population. Advances in agricultural approaches and classical breeding have produced higher-yielding plant varieties to magnify plant architecture and light-capture efficiency. From this point of view, it is extremely important to support photosynthesis research in developing countries.

In the twenty-first century, we will have to face a more difficult task—to intensify our understanding of plant regulatory mechanisms and to construct effective applications to improve plants for a rapidly changing environment. However, by 2050, the global population is estimated to increase from its current 7.6 billion to 9.7 billion, and consequently, the recently plateaued yields of the major crops must be enhanced to maintain the food supply. The prospect of world hunger looms again. Photosynthesis is influenced by multiple environmental factors, including high temperature, drought, salinity, high and fluctuating light, mineral nutrition, and CO₂ concentration (Brestic et al. 2018; Ferroni et al. 2020; Ibrahimova et al. 2021; Li et al. 2021). The question of how plants grow under changes in these environmental conditions and how photosynthesis optimization occurs are some of the most important and interesting questions in studying plant growth, for if we are able to quantify the optimal environmental conditions that maximize photosynthesis, they can be employed in controlled environments to increase crop productivity (Aliyeva et al. 2020; Hussain et al. 2021; Mishra et al. 2021; Yan et al. 2021). We want to improve the structural and functional properties of the photosynthetic apparatus so that modern varieties are more efficient and effective in the use of water and mineral nutrition resources and more tolerant to environmental changes.

Different ploidy levels of chromosomes probably play an important regulatory role in the photosystems and antioxidative systems of plants (Mao et al. 2018; Chovancek et al. 2021). Despite much successful research, there is still a lack of information on how plants can more efficiently transform solar energy and better fix CO₂, how plants respond to combined environmental stress factors, and how they will be able to cope with the consequences of climate change in the twenty-first century (Li et al. 2019). Therefore, there is a

great necessity for reviving research into the ecophysiology of photosynthesis.

Research into photosynthesis in model plant organisms is extremely important in light of new knowledge of mechanistic research (Shimakawa and Miyake 2019; Kohga et al. 2021), but the results of agricultural crop research are particularly important and directly applicable in practice (Petrov et al. 2018; Ramazan et al. 2021).

The aim of this special issue is to help elucidate the current progress of this research by providing a combination of reviews and original research articles.

This special issue focuses on a wide range of issues that can initiate new approaches, deeper research, new applications, and the motivation to focus plant research more on the unique process of photosynthesis.

As the only yield determinant that is not close to its biological limits, photosynthesis gives us a great opportunity to improve crop yields. Thus, understanding the mechanism of its manipulation is necessary to make a step toward the solution of global food security. We assume that the twenty-first century will be a period of intense photosynthetic research.

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