

Editorial overview: Physiology and metabolism: Harnessing genetic variation in metabolic traits to understand trait evolution and improve the sustainability of crop production

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At a time of unprecedented challenges for humankind and the environment we live in, understanding, preserving and exploiting genetic diversity in metabolic traits offers an opportunity to improve the sustainability of crop production while protecting ecosystems biodiversity. Plants are sessile organisms and evolve mechanisms of adaptation to the surrounding environment that enhance their fitness and chances of survival. With the climate becoming increasingly unpredictable and volatile, physiological and metabolic plasticity enables plants to thrive in natural ecological and agricultural environments. In this editorial we provide an overview of the potential to exploit genetic diversity to address the challenges of improving the sustainability of crop production and conserving biodiversity.

Gaining fundamental understanding of metabolic trait evolution and adaptation relies on investigation of genetic variation, the naturally occurring differences in DNA sequence observed within a species. Such differences in sequence arise from random mutations and may be passed on to subsequent generations. Some of these mutations may improve fitness and therefore become more common in a population while others may reduce an individual's fitness and are likely to be lost over time [1]. The result of the evolution of biochemical and metabolic traits is increased complexity and tremendous plant diversification [2]. Our ability to understand how evolution resulted in complex agriculturally and ecologically important traits depends upon investigation of genetic variation. Articles in this issue explore the evolution of genetic variation in C₃ and C₄ photosynthesis [3,4], production of an incredible diversity of specialized metabolites [5], and adaptation to the circadian clock [6]. These studies highlight the development of an enabling and rich toolbox of genomic, metabolomic and proteomic approaches for quantifying variation in complex and diverse phenotypic traits.

Additionally, there is vast and underutilized genetic diversity within and across the relatively small number of agronomically important plants. Of the more than 14,000 edible plant species on the planet, it is estimated that only 150-200 are used by humans [7], and only three species (rice, maize and wheat) contribute 60% of the calories consumed by humans [8]. Loss of genetic diversity occurred during domestication and through plant breeding, and imposes a genetic bottleneck on crops [9]. Although

variation in metabolic traits is greater across different species (interspecies), intraspecies variation exists [3,10] and can be exploited for crop improvement in breeding programs. By accessing landraces and wild relatives, allelic variation lost during breeding can be re-introduced into crop germplasm [11]. This potential for legumes, the third-largest plant family on the planet, is explored by Zhang and co-authors who describe recent progress in using genetic variation in wild legume species to improve biotic stress resistance, abiotic stress tolerance, nutrition, and phytochemicals in crops [12].

Improving the sustainability of agriculture is a critical need if we are to address the growing demands of a more populous and affluent global population, as well as maintain functional natural ecosystems [13]. Critically, increasing sustainability of agriculture has a major impact on climate regulation as agriculture is an important contributor of greenhouse gases and driver of global change. Genetic variation in traits that can improve resource use efficiency in crops is well established, and articles in this issue address the potential to harness natural variation to improve water use efficiency [14], photosynthetic efficiency [10] and nitrogen use efficiency in cereals [15].

The world is warming and the climate is becoming increasingly volatile and unpredictable. Efforts have been made to identify protein isoforms available in nature that operate optimally at warm temperatures. In this issue, Galmés and co-authors provide an overview of natural diversity in the temperature response of the CO₂-fixing enzyme Rubisco and show that replacing the native enzyme present in wheat and maize with enzymes that show superior performance at warm temperatures may enhance and future-proof the productivity of these crops by doubling their carbon assimilation potential [16]. More importantly, it is becoming increasingly apparent that photosynthetic optimality needs to be adjusted to a broad spectrum of temperatures if crops are to be productive in an increasingly volatile growing environment.

Although our understanding of genetic variation in plant metabolic processes such as photosynthesis has greatly improved over the past decades, we are still unable to measure accurately and with sufficient throughput the efficiency of photosynthetic responses to rapid changes in the environment. Murchie and co-authors [17] review evidence suggesting that dynamic changes in photosynthesis in response to rapidly changing environmental cues (i.e., the “photosynthome”) significantly impact crop yields. Moreover, the regulation of photosynthetic metabolism is still poorly understood. As highlighted by Rosa and Abreu in this issue, genetic diversity exists in regulatory mechanisms affecting plant physiology and metabolism, and a better understanding of such regulatory mechanisms will unlock the potential to exploit novel strategies to improve crop performance [18].

Unfortunately, land use change, urbanization encroaching on natural spaces, and loss of habitat with global change challenge the protection of genetic diversity within the world’s species. The planet is currently in the midst of the sixth mass species extinction event, losing species at an estimated rate 100-1000 times greater than during the Holocene [19,20,21]. With these species loss also comes the loss of genetic variation and the potential loss of opportunities to understand trait evolution and adaptation. The articles in this issue serve as an important reminder of the need to conserve genetic variation.

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