High throughput Phenotyping for Abiotic Stress Selection

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ABSTRACT

Climate change is making the cropping environment more variable on all geographical and temporal aspects. Plant breeding techniques that focus on the physiological restrictions on crop performance in specific habitats are required to maximise yield potential in good years and preserve yield stability during circumstances of increasing abiotic stress. This means that the breeding strategy needs to be characterized by habitat clustering, dynamic modelling of conditions within target populations of environments, GxE forecasts, and the development of screens that facilitate genetic gain selection. With the use of related technologies and high-throughput phenotyping (HTP), these issues can be resolved. There is great potential for whole-genome selection—which is employed increasingly often in breeding programs to be supplemented by non-destructive HTP analysis of the morphological, biochemical, and physiological properties of plant canopies. Numerous cutting-edge analytical methods, including deep learning and machine learning, along with sensors, enable quick, objective, and repeatable evaluation of sizable breeding populations. HTP can be used to examine secondary features that influence water and radiation usage efficiency for selection at the start of a breeding plan.

INTRODUCTION

The phenotyping of traits linked with physiological responses to abiotic stress in a field setting remains a bottleneck impeding large-scale crop improvement (**Aasen *et al.* 2020**). The pressures of population growth and climate change (CC) increase the urgency for methods to further increase the rates of genetic gain required in environments with elevated levels of abiotic stress. In the light of a changing climate, plant breeders are faced with the challenge of identifying the key stressors of particular target population of environments and selecting for traits within available genetic resources to confer advantageous responses. Recent advances in genomic selection (GS) strategies and trends towards physiological breeding require accurate infield high-throughput phenotyping (HTP) methods for the development of selection models that utilize indirect traits in selection for yield. While the implementation of in-field HTP pipelines is becoming commonplace, scaling such systems up to suit Multi Environment Trials, with multiple data sources across varying physical and temporal scales, remains a major challenge. Data science revolution, which is providing numerous opportunities for improvements in selection accuracy and intensity, combined with expanding capacity in HTP, environtyping and modelling, needs to contribute to address this issue. A major adaptation strategy for producers will be the selection of crop varieties able to withstand abiotic stress conditions. Plant breeders therefore need strategies that improve selection accuracy for responses under abiotic stress and account for increasing variability at all scales of the breeding programme.

Climate change and abiotic stress

Climate change has evoked the variations in temperature, rainfall and atmospheric conditions and has exposed the plants to harsh and extreme climatic conditions that adversely affect the morphological, developmental, cellular and molecular processes in plants. The unfavorable environmental conditions such as high temperature and enhanced CO_2 concentration greatly influence the growth and yield of the plants. Plants are very sensitive to climate change due to their long-life span that renders it difficult for them to adapt to changing environmental conditions. Variation in temperature under natural conditions can affect plant growth and reproduction, and adverse climatic fluctuations damage the molecular mechanisms related to growth, thus affecting the development of plants. Increase in temperature has posed a detrimental effect on the growth and yield of crop plants. Due to fluctuations in climatic conditions the lowland areas of cultivation will get converted into heat-stressed environments with a very short-season for crop production. Moreover, mathematical modelling techniques predict that production of cereals in Southeast Asia and Southern Africa will get altered by changing climatic conditions if new approaches for its improvement are not found. Climate change impact on plant development is attributed to the altered photosynthetic carbon assimilation mechanisms. Further, drought stress induced due to changing climatic conditions severely hampers stomatal conductance, plant water relations, CO_2 assimilation and photosynthetic pigments leading to reduced productivity in plants.

Abiotic stress and selection strategies

Abiotic stress events fall on a temporal continuum, which spans the short term through to the long term: events can occur over a few hours or days, while they can also be integrated across entire growing seasons and years, e.g. high water use and a depleted soil profile in one year may have direct impacts on the subsequent season. Selection for traits responsive to short-term stress involves the identification of the affected developmental stage and the implementation of screening systems to identify adaptive genotypes. Selection for longer-term abiotic stress poses a more complex challenge, as effects are generally integrated across entire seasons, and plant responses are based on more complex polygenetic factors that relate to higher level traits. Screening for these responses requires systematic observation of traits in order to dissect components of adaptation down to key physiological processes (**Tardieu 2012**). Accelerated phonological development caused by elevated mean temperatures, and the challenge of matching water supply and demand in drought prone environments are examples of challenges posed by such sources of abiotic stress.

In-field HTP typically utilizes remote and proximal sensing techniques to measure the morphological, biochemical and physiological characteristics of crops, and these characteristics can then be synthesized into quantitative traits useful for selection in Breeding Programs. HTP has been demonstrated as suitable for the screening of both short-term and long-term sources of abiotic stress. The ability to make rapid assessments of entire breeding trials means that the confounding effects of short-term environmental changes can be reduced, maximizing genetic signal and reducing experimental noise (**Araus *et al*. 2018**). This is particularly relevant for traits such as canopy temperature (CT), whereby rapid, whole-trial measurements are required to avoid changes in ambient temperature, radiation or wind, e.g. as measured from a piloted helicopter system or UAV (**Perich *et al*. 2020**). Under future climate scenarios, adaptation to heat and drought environments will likely be improved through breeding for water use efficiency (WUE), total water use and harvest index (HI). While crops bred for WUE have exhibited greater yield in terminal drought environments, in areas with moderate stress, WUE can negatively impact yield. In these situations, effective use of water or agronomic WUE may be a more relevant physiological trait to target, since it involves consideration of the amount of economic yield per unit water utilized by the crop.

HTP opportunities, bottlenecks and considerations

Understanding the quantitative variations in phenotypic expression is paramount to breeding crops resilient to abiotic stress. While yield and quality remain the predominant metrics by which selection in conventional BPs is based, a large body of theoretical and empirical evidence shows that selection of secondary traits can accelerate yield gains. Whole-genome selection strategies, which have further potential to improve complex trait selection in plant and animal breeding. By combining HTP with whole-genome selection methods, an understanding of the genetic components relating to complex physiological processes can be developed. In-field HTP can non-invasively measure the properties of crop canopies, individual plants and their organs, avoiding the substantial efforts involved with manual phenotyping methods for abiotic stress selection. HTP involves the use of fixed installations, handheld and mobile systems designed to capture spectral reflectance, classify objects and measure volumetric and spatial information about crops in the field.

Non-invasive tools to assess plant responses to abiotic stresses

Due to the development of molecular biology and methods to locate the genes in the chromosome, the study on genomes of agricultural plants has increased. But this knowledge is still lacking unless the linakge between the reactions of plants to certain environments and external treatments with genetic information about the crops that have been collected. Hence, plant phenotyping, sometimes referred to as plant characterization, is given more attention now a day. Traditional plant phenotyping techniques have not produced a functional map by utilizing genotype and phenotype. Phenomics is an emerging field of study that has gained importance due to its emphasis on solving these drawbacks. High throughput phenotyping in response to demographic and climatic circumstances is made possible by phenomics technology. Phenomics incorporated high dimensional phenotypic data at several organization levels in order to characterize all of a genome's phenotypes.

A plant phenotype consists of structural, physiological, and performance-related traits of a genotype in a given environment. Plant phenotypes are inherently complex because they result from the interaction of genotypes with a multitude of environmental factors. This interaction influences structural traits associated with developmental and growth of plants as well as physiological traits contributing plant functioning. Both the structural and physiological traits eventually determine plant performance in terms of biomass and yield.

Plants adapt their morphology, anatomy, phenology, and cellular metabolism to many elements of their developing environment. Consequently, under favorable and unfavorable settings, crop growth, development, and production rise or decrease, accordingly. A significant portion of the progress made thus far in raising agricultural production may be credited to empirical selection for yield and yield components. This was more noticeable in environments that were conducive to development than in those that were influenced by salt, high temperatures, drought, etc. As a result, characteristics linked to resistance to these abiotic challenges are receiving more attention these days. Pertaining to plant responses to stressors, additional genes linked to such qualities hold the keys to future improvement, since gene action in cellular and molecular mechanisms manifests itself.

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