Phenotyping Horticultural Crops for Abiotic Stress Tolerance

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Abstract

Plants' growth and development is dependent on the environmental conditions, and they require optimum conditions not only at critical phenological stages but during the entire growth cycle. Crops must be grown in optimum environmental conditions to attain highest genetic yield potential, which is seldom attained due to occurrence of abiotic stresses at critical stages in field conditions. The adverse impacts of abiotic stresses have always challenged the farmers and scientists alike to devise adaptation strategies to overcome adverse impacts and sustain productivity. Plants, through constant and complex interaction between genotype and environment, have developed inherent ability to survive adverse environmental conditions. To unravel this, extensive efforts have been made to characterize crop plants through screening for abiotic stress tolerance and elucidate the biochemical and physiological mechanisms imparting such tolerance. Modern biology has attempted to understand how genotypes manifest to specific phenotypic characteristics, and efforts are also underway in development of cultivars with useful characteristics. The assessment of phenotype from genotype of a plant poses many difficulties due to contribution of large number of genes to the plant's phenotype under various environmental conditions. However, the concerted efforts by scientists have enabled to identify traits for large-scale screening of germplasm both under controlled and field conditions. Plant phenotyping requires the availability of a diverse germplasm, and the simulation of a target environment that crop is expected to experience under field conditions. The simulated environment needs to be dynamic or constant depending on the need. Temporal and spatial changes during the crop growth also need to be kept

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in mind. Ultimately, the phenotyping efforts need to comprehensively encompass the traits desired to overcome the adverse effects of abiotic stresses under field conditions. Now, phenotyping has been taken to new level using high-throughput phenotyping combining imaging and information technologies. The phenotyping options available for abiotic stress tolerance for horticultural crops are discussed here.

14.1 Introduction

Plants have adapted to different agro-ecological regions, and their growth and development is dependent on the growing environmental conditions. Plants require optimum environmental conditions not only during the critical phenological stages but also throughout the entire growing period. To attain the highest genetic yield potential, a crop must be grown in an environment that meets the optimum conditions. Even though the crops are well adapted to a particular agro-ecological region, they seldom attain the genetic yield potential due to occurrence of abiotic stresses at sensitive stages (Fitter and Hay 2002). Though the crops can be grown with minimal adjustments under such circumstances, the unfavourable environmental conditions at critical stages of crop growth lead to lower yields. Since horticultural crops are both annual and perennial in nature, the abiotic stresses impact them differently when compared to agriculture crops. Additionally, the impacts of climate change and climate variability are projected to steadily manifest directly from the frequency and intensity of droughts, floods and high-temperature episodes. Climate change is expected to result in long-term water shortages, droughts, worsening soil conditions and high-temperature extremes during the cropping season (IPCC 2007). Such adverse impacts during the sensitive stages of crop growth have always challenged the farmers and scientists alike to devise adaptation strategies to overcome adverse impacts and sustain productivity.

Diverse agro-climatic conditions available in India provide ample opportunity to grow a variety of horticulture crops round the year, placing India as the world's second largest producer of fruits and vegetables after China (Indian Horticulture Data base 2010). Horticulture is a high-priority sector of agriculture where impacts of climate change will have profound implications on the livelihood and nutritional security. Though some spices and plantations are location specific, horticulture crops like fruits, vegetables, flowers, medicinal plants and tubers are grown in diverse climates from tropical to temperate conditions. In order to sustain horticultural production with challenges of climate change and climate variability, we need to develop strategies to manage abiotic stresses. The strategy needs two pronged approach, one developing superior tolerant cultivars and another developing suitable cultural practices to manage abiotic stresses occurring at critical stages of crop growth and development. Though resorting to adaptations through cultural practices provides immediate relief from abiotic stresses, developing superior tolerant cultivars is a long-term approach. Adapting such an approach needs thorough phenotyping of the available germplasm for tolerance to abiotic stresses and consequently identifying tolerance traits and most suitable genotypes.

Modern biology has been putting in enormous efforts to understand how genotypes manifest to specific phenotypic characteristics. The efforts are also underway in the development of cultivars with useful characteristics. The assessment of phenotype from genotype of a plant poses many difficulties due to contribution of large number of genes to the plant's phenotype under various environmental conditions. Plant phenotyping helps in description of the processes involved and assessment of the phenotypes that could have the desirable traits. Plant physiologists are facing the need to quantify individual phenotypes that correspondingly match the individual genotypes.

The critical stage for measuring the phenotypic traits is very important because at critical stage, correlation between the trait and final yield is the highest. The efforts in the direction of phenotyping and consequent genetic enhancement need to be oriented in identifying the critical stage at which variability in the target traits plays an important role. This approach helps in making the critical stage more diagnostic for a particular trait. We need to further consider the variability in the target traits during the complete growth cycle of the plant.

Extensive efforts have been made to characterize crop plants through screening for physiological and biochemical mechanisms adopted by plants to tolerate abiotic stresses (Rahman et al. 2004; Aazami et al. 2010; Bananuka et al. 1999). The large-scale screening of germplasm using certain traits has also been attempted in many crops both under controlled and field conditions. Further, phenotyping has been taken to new level of high-throughput phenotyping combining imaging and information technologies. In this chapter, the attempts made by several scientists to characterize, and phenotype horticultural crops for abiotic stress tolerance are discussed.

14.2 Evaluation for Physiological and Biochemical Mechanisms

Plants, through constant and complex interaction between genotype and environment, have developed inherent ability to survive adverse environmental conditions. The response to abiotic stresses is a complex phenomenon, because it involves simultaneous responses at whole-plant, organ, cellular and molecular levels. Overall, the plants respond through complex intracellular signalling cascades that regulate biochemical and physiological acclimation. Thus, the outcome of constant interaction of genotype and the environment is the plant's phenotype. The phenotype could be considered as a multi-scale description of an organism's attributes displayed in space through time. It is expressed at various organizational levels, from molecules to metabolic networks to cell development and physiological processes, finally integrating into the yield-determining characteristics. Thus, the expression of plant's phenotype becomes dynamic under the influence of environmental variables.

An understanding of physiological and biochemical events associated with abiotic stresses is essential for enhancing the tolerance of the future cultivars. Considerable progress has been made to elucidate plants' physiological and biochemical mechanisms that enable them to tolerate abiotic stresses (Chaves et al. 2003; Chaves and Oliveira 2004; Chandrashekar et al. 2012). The techniques have been mainly employed to identify the differences in metabolism and physiological processes and traits imparting tolerance. Thus, studies have deciphered the role of such mechanisms imparting tolerance. The efforts directed primarily to screen genotypes for tolerance to abiotic stresses in target environments, both in controlled and field conditions, have helped physiologists in exploring the diversity among germplasm for tolerance traits. This understanding has further helped plant breeders in developing cultivars possessing tolerant to abiotic stresses.

The traits like gas exchange characteristics have been observed being influenced by abiotic stresses and are higher in the tolerant cultivars compared to the susceptible ones (Grzesiak et al. 1999; Ekanayake et al. 1998; Zhang Jie1 et al. 2012); differences in intrinsic water-use efficiency (Pimentel et al. 1999; Condon et al. 2002), a measurement dependent on gas exchange characteristics, have also been observed in Phaseolus vulgaris. Screening of tomato germplasm for root traits has shown the drought-resistant mutant derivatives showed significantly superior root characters. The root length, feeder root per 5 cm, tertiary root and root fresh weight were of primary importance and were strongly and positively associated with drought resistance (Kulkarni and Deshpande 2007). In bean plant, differences in water relations under water stress have been observed (El Tohamy et al. 1999). Hormonal regulations like ABA being the central regulator of plant responses to environmental stresses (Cramer 2010) and the changes in ABA were higher in the tolerant pea cultivar (Upreti and Murti 1999). Other subcellular processes such as photo-protective mechanisms including antioxidant systems have been studied (Reddy et al. 2004). In banana, higher ascorbate peroxidase and superoxide dismutase activities were associated with greater protection against water stress-induced oxidative injury (Chai et al. 2005); the regulation of water flow via aquaporins (Bramley et al. 2007) and signalling through abscisic acid help in coordination of abiotic stress tolerance processes (Shinozaki and Yamaguchi-Shinozaki 2007). Ultimately, phenotyping efforts should address the issues of yield through the evaluation in target environment.

Much progress has been made in identification and characterization of the mechanisms that impart tolerance to abiotic stresses. Plants respond to these abiotic stresses partly by activating the expression of stress-responsive genes, whose products are responsible for increasing the plant's tolerance (Kahn et al. 1993; Ravishankar et al. 2011). The understanding of how stress-responsive genes are activated by abiotic stress will help us to breed or engineer stress-tolerant crop plants. With the availability of complete information on a couple of plant genomes and of various genomics and proteomics tools, knowledge on plant abiotic stress responses has advanced at a great pace in the last few years. However, utilization of genomic information for crop improvement aimed at tolerance to abiotic stresses is severely constrained by lack of a one-to-one correspondence between phenotypes and genotypes. Though scientists have evolved techniques and procedures to evaluate plants for abiotic stress tolerance, there is a dearth of phenotyping procedures that are accurate and reproducible. Therefore, to bridge the gap, concerted efforts towards fine phenotyping for abiotic stress responses should be one of the major areas to focus upon. Now, plant phenotyping is a major field of research, and establishing robust protocols and screening methods is the need of the hour. Here the available germplasm of a crop of our interest is used to unravel the traits imparting tolerance to abiotic stresses, and this has been possible due to the advances in molecular technologies like sequencing. The genotypes having tolerance traits could be further subjected to molecular characterization, identification of candidate genes (Cocuron et al. 2007) and proteomics analysis (Schilmiller et al. 2010) and construction of metabolic or regulatory networks.

14.3 Need for Target Environments

The diverse germplasm of the crop of our interest needs thorough evaluation in the target environments to identify traits responsible for enhanced performance under the imposed conditions. Target environmental conditions need to be simulated and monitored throughout the experimentation. Since phenotyping is the analysis of plant's quantitative traits expressed through the interaction of plant and its growing environmental conditions, simulated target environment under controlled conditions should match the conditions the crop normally experiences in field during its growth and development. Hence, simulated environment could be dynamic or constant depending on the need. In order to simulate dynamic target environments, the temporal and spatial changes need to be maintained under field conditions.

14.4 Evaluation Under Controlled Conditions

Although field phenotyping is the best option to select genotypes of our interest in the target environment for yield and its component, the phenotyping in controlled environment facilities is advantageous for imposing abiotic stresses uniformly, which is not possible in field conditions. The studies on influence of abiotic stress factors like excess or limited moisture stress, high temperature and salinity are conducted under controlled conditions. The controlled conditions under which plants are grown should be relevant to the conditions prevailing in the field (Izanloo et al. 2008). Evaluation under controlled conditions is advantageous in terms of collecting data at a particular stage when the genotypes being tested differ in durations to attain certain phenological stage. Growing plants in pots allows for strict control of water stress imposed on test genotypes and the homogeneity of stress severity; such control is seldom achieved under field conditions, particularly when genotypes under test differ in phenology and/or biomass.

Phenotyping becomes more complex when the target traits are quantitative in nature and when the environmental conditions influencing target trait vary during course of the day, for example, temperature, light intensity and soil water status. In such situations, the phenotype of the plant is dynamic, and it is better defined by a series of response curves to environmental stimuli (Hammer et al. 2004; Tardieu et al. 2003, 2005). This approach is again time consuming and requires a tight control of environmental conditions (Tuberosa 2011). In addition, the time of measurement and sample collection become more important for morpho-physiological traits that fluctuate widely during the circadian cycle. Identifying the most appropriate time for measurement and sample collection is very critical for traits like plant water status, ABA content, stomatal conductance, leaf rolling and leaf temperature. Though the most appropriate time could be identified, measurement of certain traits is time consuming in a large number of plants. Such instances introduce variations in the data proportional to the duration of data collection. Here, the traits that encompass variability hold greater potential to minimize or altogether eliminate the effects on trait expression due to time of the day. In controlled condition study at 35°C day and 27°C night temperature, high-temperature-tolerant tomato line from AVRDC CL-5915-206 DG 2-2-0 had significantly higher leaf area and total biomass compared to susceptible cv. Arka Saurabh. No fruit set was observed in Arka Saurabh, while 40% fruit set was observed in CL-5915-206 DG 2-2-0 (Srinivasa Rao 1996). Genetic variability for temperature tolerance could be studied by exposing the seedlings to induction temperature. The temperature induction response (TIR) technique (Kumar et al. 1999; Srikanthbabu et al. 2002) is used to identify genotypes tolerant to high temperature. In this technique, the seedlings are exposed to severe challenging temperatures and allowed to recover at room temperature. The surviving seedlings at the end of the recovery period are selected as thermotolerant. Here it is hypothesized that induction stress is a prerequisite for the optimum expression of stress-responsive genes that bring about the intrinsic differences in stress tolerance among the different germplasm lines that are the same in terms of other characteristics. This technique has been used in crops like tomato (Senthil-Kumar and Udaykumar 2004) and pea (Srikanthababu et al. 2002).

14.5 Evaluation Under Field Conditions

Ultimately, evaluation of crop plants for yield performance under particular abiotic stress needs to be done under field conditions. Field phenotyping helps to identify tolerance traits in the ultimate target environment and helps in evaluating many genotypes at a time. Unlike controlled growth conditions, in field evaluations, there are certain factors which impact the quality of the phenotypic data to be collected (Tuberosa 2011) listed the following factors to be evaluated carefully to ensure the collection of meaningful phenotypic data in field experiments under water-limiting conditions. The factors are the experimental design, heterogeneity of experimental conditions between and within experimental units, size of the experimental unit and number of replicates, number of sampled plants within each experimental unit and genotype-by-environment-by-management interaction. Though the field evaluations are conducted in the ultimate target environments during the cropping season, slight variability in the environmental conditions or crop management during the experimentation might influence the plant's phenotype. Thus, the variability caused by these factors must be kept to the minimum so as to collect quality phenotypic information. In field evaluation, techniques like measuring canopy spectral reflectance (Gutierrez et al. 2010) and screening under high-temperature stress (Hazra et al. 2009) and drought stress (Ashraf et al. 2005; Rahman et al. 1998) are employed. The phenotyping methodologies like line source irrigation, withholding irrigation to impose water stress (Rao and Bhatt 1992), imposition of salinity stress and conducting evaluation trials during high-temperature periods in the hotspot areas are a few techniques that are followed under field conditions.

14.6 Water-Use Efficiency (WUE) as a Trait

Water is the major component of most horticultural crops as they are sold by fresh weight; thus, there is a necessity to maintain optimum water content of horticultural produce. The water available for agriculture in general and horticultural production in particular is at stake due to the increasing demand for fresh water for domestic consumption. Moreover, the increase in global average temperatures is likely to change the precipitation patterns and intensity resulting in water scarcity. Under climate change conditions, availability and quality of water will create bigger challenges (IPCC 2008). Such climate uncertainties create the need for efficient use of available water resources. Thus, the knowledge of traits contributing for better performance of crop plants under water stress conditions need to be enhanced. As we face the challenges of sustaining productivity even under the water-limiting conditions, traits like water-use efficiency (WUE) become more important. WUE is the amount of dry matter produced to the amount of water used by the plant through evapotranspiration. Hence, it involves the physiological processes that influence both dry matter accumulation and water use by the plant.

Although management techniques are playing an important role in enhancing water use and WUE in horticultural crops, there is a need to complement these efforts by improving WUE at the whole-plant level. This has become an important component of limited water stress resistance breeding. Selecting genotypes having high WUE alone may not be rewarding, as it may be associated with low biomass. Hence, selecting genotypes with high biomass potential and with high WUE under a stress environment may be more appropriate. Understanding the mechanism enabling root growth in a water-deficit environment and linking it with molecular markers may help to select this trait in segregating populations. Hence, a multidisciplinary approach, in pyramiding traits imparting drought tolerance while retaining the productivity potential of a genotype under irrigated environment, is desirable. The gravimetric approach for quantifying the water use and water-use efficiency of the test plants is very laborious and time consuming. Hence, scientists have depended on the surrogate methods of assaying the WUE.

Measurement of carbon-isotope discrimination (CID) as an indicator of transpiration efficiency is being used as a ‘surrogate’ measurement in crop physiology and plant breeding (Richards et al. 2010). Plants discriminate against the heavy isotope of carbon (^{13}C) naturally present in atmospheric CO_2, both in the process of CO_2 diffusion into the leaf and also in the metabolic processes of photosynthesis (Condon et al. 2004). This isotopic discrimination is reflected in the isotopic signature of plant dry matter. In C_3 crops, CID values are strongly related to stomatal conductance and transpiration efficiency for a given photosynthetic capacity (Condon et al. 2004; Richards et al. 2010). CID technique has proven to be a useful research tool to evaluate the genetic variation in transpiration efficiency of the available diverse germplasm and further breed the commercial varieties with greater water-use efficiency and yield. This technique involves the collection of samples at the end of the growing season and quantification of isotopic composition that reflects the overall effect of the entire growing season. Since this technique helps in avoiding collection of multiple samples at different phenological stages, it would be possible to phenotype large number of germplasm with limited number of plants. The study on tomato suggested that WUE can be increased by selecting low-carbon-isotope discrimination, but selecting low-carbon-isotope discrimination alone may identify a subpopulation of small plants (Martin et al. 1999). In grapes, carbon-isotope discrimination (Δ) of laminae dry matter ranged from 20.8% to

22.7%, and there was a negative relationship between transpiration efficiency and carbon-isotope discrimination. A large proportion of variation in transpiration efficiency could be attributed to variation in stomatal conductance. Genotypic variation in photosynthetic capacity was also an important component of variation in transpiration efficiency (Gibberd et al. 2001).

14.7 Canopy Temperature Depression (CTD)

Canopy temperature depression measurement technique indicates the overall plant water status in terms of amount of water extracted from the rhizosphere and water lost from the canopy through evapotranspiration. Thus, this technique provides information on the rhizospheric size, depth and functionality in accessing soil moisture. It can be used as a fast, inexpensive screening tool of root features (Blum et al. 1982). Again in this technique, timing of measurements of canopy temperature differences between treatments is a critical factor. In field, even well-watered healthy plants, under conditions of high evapotranspirative demand, may shut their stomata before noon. This becomes relevant when different genotypes are evaluated for their capacity in resorting to water loss avoidance strategy. In this case, the timing of measurements to bring in good discrimination among genotypes needs to be determined for specific conditions. As the water stress progresses through the day, considerable readjustment during subsequent samplings is needed. An additional factor to be considered when measuring canopy temperature is the effect of leaf wilting, folding or rolling under stress (Grant et al. 2006, 2007; Leinonen et al. 2006). The plant canopy architecture will influence leaf temperature not only through the angle of leaves to the light source but also through the degree of self-shading in the canopy (Zheng et al. 2008). To a certain extent, the influence of self-shading can be reduced if the most suitable view angle is used, although different opinions have been expressed in this regard (Grant et al. 2006).

14.8 Need for Comprehensive Phenotyping

The ultimate goal of phenotyping is to reduce the genotype–phenotype gap, especially for quantitative traits. Keeping a good record of meteorological parameters like rainfall, temperatures, wind, evapotranspiration and light intensity allows for more meaningful interpretation of the results and identification of the environmental factors limiting yield (Sadras 2002). It also involves diverse genetic material, accuracy and precision of measurements and experimental conditions that represent target environment. For a number of traits such as stomatal conductance and flow of xylem sap measured with mechanical or electronic devices, accuracy and precision in measurements require calibration of the instrument prior to data collection. Presently, phenotyping techniques employed by physiologists resort to destructive sampling at critical stages. The field phenotyping approach involves measurements that are highly laborious, expensive and time consuming. The techniques involving manual measurements where each variable is measured separately do not allow the season long monitoring of complex traits. Such inherent problems faced in field phenotyping have led to application of remote sensing technologies.

Hence, the need for a comprehensive phenotyping, which captures the minute phenotypic differences among the genotypes, is being addressed through phenomics. It is an area of science employed to characterize phenotype of a plant in a more rigorous and highly efficient way and ultimately relate these phenotypic traits to the associated genes. Phenomics could be described as simply ‘high-throughput plant physiology’ (Furbank and Tester 2011). Thus, the phenotypic parameters could comprise morphological parameters from cell size to plant height and yield on one hand and molecular characterizations like fingerprints and transcript profiles on the other. Phenomics deals with large-scale collection of phenotypic data and its analysis. Though the traditional approaches of phenotyping were employed earlier to screen the available germplasm, this approach is distinguished by its scale and scope. It employs large populations of germplasm with an aim to identify genetic variations. Thus, the individual genotypes are screened for desirable traits with accuracy and throughput. The phenomics approach subject's plant to target growing conditions under which the traits are phenotyped and plants are closely monitored throughout the testing period. The process involves collection of data on the phenotype and experimental conditions in formats that could be analysed in detail.

The recent developments in plant phenomics as an emerging field have led to development of technologies to characterize plant performance and dynamics of plant structures and functions. The approach involves achieving high-throughput and high-content information using appropriate experimental designs. This involves simultaneous development of novel technologies of sensors and algorithms for automation of analyses. Thus, phenomics has developed into a scientific field that aims to accurately quantify phenotypic traits as a measure of plant performance. It involves multidisciplinary approach with studies at cellular, leaf and whole plant and further from crop to canopy. The plant phenomics would provide a comprehensive and continuous analysis of plant growth and performance employing new technologies. The phenomics facilities provide non-destructive and destructive measurements of above and belowground plant parts during the course of plant life cycle. Through the measurements of changes in leaf size, leaf temperature and plant growth over time, plant phenotyping helps in identifying tolerant genotypes from the diverse genetic pool available in both cultivated and wild relatives. An important role for these technologies in delineating next generation traits is 'reverse phenomics'. For example, for a phenotype that appears drought tolerant, understanding the basis for this trait, at the physiological and genetic level using high-resolution phenomics tools, provides us the knowledge base to find the next set of leads necessary to underpin progress in plant breeding.

Phenotyping can take place under laboratory, greenhouse or field conditions. Under laboratory conditions, environmental factors may be controlled and varied as desired and manipulating one or more factors in dedicated experiments. Through this controlled approach, the influence of specific genetic and chemical factors interacting with a limited number of environmental factors can be investigated. In contrast, field conditions are highly variable, fluctuating in time and space (Rascher and Nedbal 2006; Schurr et al. 2006; Mittler and Blumwald 2010). Despite this, new technologies capable of high-throughput phenotyping coupled with environmental monitoring at high spatial and temporal resolution can deliver data sets large enough for statistical approaches. For example, imaging spectroscopy can provide high-resolution pictures from ground and airborne platforms that contain high-resolution spectral data of millions of pixels (Rascher et al. 2009). Single spectra can be attributed to single plants or experimental plots and related to plant functional traits (Ustin and Gamon 2010). Growth and development of plants under abiotic stress conditions could be quantified through the measurement of biomass using cameras and image analysis. These analyses would ideally identify relationships between genotype and phenotype as well as reveal correlations between seemingly unrelated phenotypes (Schauer et al. 2006). High-throughput phenotyping platforms using the technique of imaging and image analysis are available for both laboratory and controlled greenhouse conditions (http://www.lemnatec.com/; http://www.plantaccelerator.org.au/). Phenomics is a large-scale approach to study how genetic information is translated into phenotypic traits of an organism. Latest phenotyping techniques using phenomics platforms through digital imaging could help in quantifying growth and development.

14.9 Plant Phenomics for Trait-Based Physiological Breeding

The complete analysis of quantifiable traits for physiological breeding requires the application of appropriate non-invasive techniques. Once important traits or 'yield components' contributing in a germplasm are identified, either a genomic region needs to be identified to select for this trait by marker-assisted selection (MAS) in breeding or, in the case of multigenic traits commonly encountered in quantitative physiological breeding, a robust phenotypic marker is pivotal (Furbank and Tester 2011). The biomass accumulation and growth of plant, being the ultimate expression of physiological processes, are currently being scored manually. Such traits could be captured through digital imaging. The phenomics tools can hasten the speed and the precision of measuring the traits of interest. These tools using digital imaging can obtain relatively simple properties of shape and texture as proxies for some traits. The aim of image analyses is to develop three-dimensional models throughout the duration of plant growth to enable collection of much detailed information. The tools enable us to collect specific information even to the level of what happens to each organ during the course of growth. The advantage of such direct measurement of the trait of interest through imaging is that it should be possible to exploit all the genetic variation responsible for a trait. For example, early seedling vigour, an important trait for conserving soil moisture, has been shown to be related to embryo size and is currently scored phenotypically by the width of the fully expanded leaves at young vegetative stage (Richards et al. 2010). Ultimately, the role of phenomics is to enable mapping genetic elements to biological function at detail.

14.10 Conclusion

Plant phenomics can, in fact, be considered as simply plant physiology in 'new clothes', but it promises to bring physiology up to speed with genomics by introducing the incredible recent advances made in computing, robotics and image analysis to the wider field of plant biology. A multidisciplinary team in plant phenomics crosses biology, physics and mathematics, not 'just' genetics, biochemistry, physiology and plant breeding. This trans-disciplinary approach promises significant new breakthroughs in plant science. Phenomics provides the opportunity to study previously unexplored areas of plant science, and it provides the opportunity to bring together genetics and physiology to reveal the molecular genetic basis of a wide range of previously intractable plant processes. The future challenges of characterizing crop plants for desirable traits require the advances we have seen in information technology, and there is a need to build on these advances for global food security. The better knowledge of the physiological, biochemical, molecular and genetic basis of the mechanisms promoting tolerance to abiotic stress will enhance the capacity to improve crop yield under hostile environments.

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