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Plant Phenomics

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1. Introduction

Growing world population is expected to cause a "perfect storm" of food, energy and water shortages by 2030 as demand for food and energy will jump by 50% and for fresh water by 30%, as the population tops at 8.3 billion. The overarching challenge before the policy makers and agricultural scientists is how to ensure food and nutrition security for an ever-increasing population from limited and fast depleting resources under climate change scenario, especially in countries like India where sizeable population is still suffering from the triple burden of malnutrition. To meet the future demand of agricultural production, we need to develop more productive and nutritious varieties of agricultural crops which incorporate both high intrinsic yield potential and resilience under climatic stresses. This requires discovery and deployment of superior but complex traits from the vast germplasm resources being held in various genes. To meet the challenges of global food security in the changing climatic scenario. It is necessary to breed high yielding crops which can cope up with climate and it is possible by precise and accurate phenotyping which will helps breeder to exploit genetic potential of the plants. Presently available phenotyping tools are less efficient. To overcome by this problem new branch of science came into existence. It is known as "Phenomics"

2. Plant phenomics

"Phenomics" word coined by Dr. Garan, S.A., 1996. It is defined as a biological term that is related with measurement of phenomes, with the help of high-throughput technologies (Bilder *et al.*, 2009). Phenome is referred as "phenotype as a whole" in which expression of genome for a trait in a given environment. Earlier scientists used term "trait" for expression of gene. Now in phenomics a new term "phene" is introduced instead of trait. It is the expression of a gene.

3. Traditional plant phenotyping

Plant phenotyping has been a part of crop and variety selection since the time of human civilization when humans selected the best individuals of a crop species for domestication. Subsequently it has become common practice in plant breeding for selecting best genotype after studying phenotypic expression in different environmental conditions. This traditional phenotyping methods are tedious, labour intensive and many times destructive sampling is required. To find the expression of quantitative traits is very difficult it is due to high interference of environment. This Genetic and environmental interactions hide the actual performance of plants.

To overcome these circumstances leads to introduction of high-tech automated plant analysis system. In this system plants either in field or lab will be screened by using various imaging technologies. The image obtained will be fed to a computer and with the help of software data will be analysed and result is interpreted.

4. Features of plant phenomics

The practical success of this technology is due to its special features. In phenomics identification of candidate gene is done with high accuracy by using high dimensional phenotypic data on an organism at large scale and also invisible phenes are analysed. During phenotyping there is a chance of occurring false positive quantitative trait loci. It is avoided through using high through-put phenotyping tools.

5. Approaches of plant phenomics

Plant phenomics have mainly two approaches (Kumar *et al.,* 2015). Forward phenomics: uses phenotyping tools to discriminate the useful germplasm having desirable traits among a collection of germplasm. This leads to identification of the 'best of the best' germplasm line or plant variety. Use of high-throughput fully automated system has accelerated plant breeding cycle by screening a large number of plants at seedling stage. Thus, interesting phenes can be identified rapidly at early stage and there is no need to grow plants up to maturity stage in field. Now it is possible in forward phenomics to screen thousands of plants in pots running along the conveyor belt, and travelling a room containing automated imaging systems such as infrared or 3D cameras. The pots were labelled with barcodes or radio tags, so that the system can identify which pots contain which plants with interesting phenes.

Reverse phenomics: is used where the best of the best genotypes having desirable phene is already known. Now through this approach phene shown to be of value to reveal mechanistic understanding are dissected in details and subsequently the identified mechanisms are exploited in genetic improvement of crop. This is how we discover mechanism which makes 'best' varieties the best and also it is involve in reduction of physiological, biochemical phenes and ultimately a gene or genes. For example, in case of drought tolerance, researcher try to work out the mechanisms underlying the drought tolerance and find the gene or genes that are responsible for it. These genes are screened in germplasm or the gene can be transferred into a new variety.

6. Techniques in plant phenomics

Non-invasive methods for plant phenotyping at the level of whole plants and canopies plays major important role. It is highly automated by using sensors, robotics and imaging technologies (software and hardware). Table 1. provides a range of application used for lab research, screening systems and horticulture production systems. These systems are specifically designed for research and large-scale phenotyping for a limited range of species. It is generic platform and solutions enabling the simultaneous phenotypic evaluation of multiple species have not been implemented to date. This highlights that imaging methods, protocols, and workflows for large-scale phenotypic evaluation often need to be adapted and tailored to individual or small group of species (Rahman *et al*., 2015).

Table 1. Different technologies for phenotyping

Parameters	**Sensors**	**Image output**
a. 2D imaging		
Color, shape, leaf disease severity, *etc*.	Broad range of cameras	Gray or color value images (RGB channels)
Photosynthetic status, quantum yield, leaf disease severity, *etc*.	Fluorescence cameras	Pixel-based map of emitted Fluorescence
Surface temperature,	Thermal imaging system	Pixel-based map of surface

water content, *etc*.	(Near-infrared)	Temperature
b. 3D imaging		
Shoot structure, leaf angle distributions, canopy structure, *etc*.	Shoot structure, leaf angle distributions, canopy structure, *etc*.	Shoot structure, leaf angle distributions, canopy structure, *etc*.
c. High-resolution volumetric imaging		
Water content, nutrient content, *etc*.	Water content, nutrient content, *etc*.	Water content, nutrient content, *etc*.

7. Limitations

Plant phenomics with high-throughput, state-of art technologies have a great scope to advance plant science, thanks to interdisciplinary networking. Soil researches (environment), crop analysis, data researches with modelling, and sensor technologies are integrated into field and laboratories. This interdisciplinary network brings in a great speed, accuracy, efficiency to breeding, and optimized timing to crop management enabling non-biased and faster assessment of phenes. However, plant phenomics has some limitations and/or disadvantages such

- Quality of measurable data
- Data regeneration costs
- Data collection technology
- Availability of algorithms
- In addition, phenotyping techniques are dependent on some factors such as simulations, sensors, active mechanisms, and high-throughput and field-based platforms.

8. Conclusion

For making successful genetic improvement in crop plants, plant breeders first identify the desirable genotypes having target traits by screening a collection of germplasm accessions. These target traits then are combined together through hybridization. This cycle of selection hybridization-selection has been implemented on the basis of visual observation since domestication of crop plants. Though visual screening is easy and precise for qualitative and highly heritable traits, its use is less precise for quantitative phenes and those phenes, which are difficult to observe visually (physiological and biochemical traits). Moreover, vast amount of genomic resources have been developed in a number of crop species in the past. The available gene sequences and molecular markers could still not be associated with any phenes due to the lack of phenotyping of germplasm collections. For utilizing these genomic resources and identification of desirable plants, the precise phenotyping of germplasm accessions for challenging phenes is required in various crop species. In the recent past, various techniques and methodologies have been developed for screening biotic, abiotic, physiological and biochemical phenes in crop plants. These technologies have become very advanced in the era of digital science.

These plant phenomics developments are actually helping to make simply plant physiology in 'new clothes'. Thus, 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 challenges ahead in plant-based agriculture will require the scale of quantum advances we have seen in information technology in the past 20 years and we need to build on these advances for security of global food, fiber and fuel.

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