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POPULAR ARTICLE

Plant phenomics applications in crop production

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Intricacies of the subject

Plant phenomics is the high-throughput measurement of plant traits using imaging, sensors, automation and data analytics. For India, it offers a practical route to faster climate-resilient breeding, early stress detection, precision irrigation, nutrient management and yield forecasting. The technology is especially relevant as the country's food grain output reached 357.73 million tonnes in 2024–25 and horticulture output reached 362.08 million tonnes.

Introduction

Plant phenomics measures what a plant actually does and looks like under a given environment. Instead of recording a few traits manually, modern platforms can repeatedly capture plant height, leaf area, canopy temperature, biomass, flowering, disease symptoms, fruit traits and other characteristics without destroying the plant. A digital phenotype can combine RGB images, multispectral or hyperspectral signals, thermal images, 3D structure, soil information, weather data and genetic information. Machine-learning models then convert these observations into measurable traits that breeders and crop managers can use for further utilization.

Why India needs faster phenotyping

Indian agriculture spans diverse climates, soils and cropping systems. Climate variability makes it difficult to judge a genotype or management practice from a single observation. Repeated, objective measurements help separate genetic effects from environmental effects and identify plants that perform consistently under stress.

Major applications in crop production

Climate-resilient breeding: Thermal, spectral and growth measurements can identify crop lines that maintain performance under drought, heat, salinity or excess moisture. This accelerates selection for stable field performance and helps breeders develop varieties better adapted to changing climatic conditions.

Precision irrigation: Canopy temperature, spectral indices and plant architecture can reveal plant water stress and variation within a field. These measurements can support targeted irrigation and improve water-use efficiency.

Nutrient management: Spectral and canopy observations can reveal differences in plant vigour and nutrient status. When combine with

soil testing and field observations, phenomics can support site-specific nutrient diagnosis and management.

Yield and quality prediction: Repeated measurements of biomass, flowering, canopy structure, fruit size and maturity can improve yield forecasting, harvest scheduling and quality assessment.

Breeding and genomics: Phenomics provides the measurable traits required to connect DNA variation with actual plant performance. It also enables precision evaluation of complex traits.

Table 1. Selected India crop-production statistics, GoI, 2024–25

Indicator	Output	Relevance to phenomics
Food grains	357.73 million tonnes	Large-scale breeding and crop monitoring
Horticulture	362.08 million tonnes	Quality, stress and yield traits
Rice	150.18 million tonnes	Heat/water stress and yield stability
Wheat	117.94 million tonnes	Heat tolerance and grain traits

Major technologies behind plant phenomics

RGB cameras provide colour and canopy-structure information. Multispectral and hyperspectral sensors capture reflectance beyond normal visible light, while thermal cameras detect heat patterns associated with water status and plant stress. Drones extend measurements over large crop areas. Automated greenhouse and field platforms provide repeated observations at high throughput.

Artificial intelligence: AI becomes especially useful after data collection. Computer vision can segment plants, estimate traits and identify stress patterns, while predictive models can link phenotypic information with yield and quality.

Field phenomics: Drones, tractors and handheld sensors measure crops under real weather, soil and management conditions.

Controlled phenomics: Greenhouses and automated chambers reduce environmental variation so that genetic differences can be measured more precisely.

Current production statistics

Rice and wheat together accounted for approximately 74.9% of India's 357.73 million tonnes of food grain output in 2024–25. Their large production scale makes them important targets for phenotyping traits associated with heat tolerance, water-use efficiency, disease response and yield stability. Pulses and millets have smaller total production volumes but remain highly important for drought resilience, nutritional security and climate-smart agriculture.

India's emerging plant-phenomics ecosystem

India supporting controlled and climatic-related phenotyping research. Earlier Indian platforms also demonstrated the potential for high-throughput plant measurement. ICRISAT's FieldScan was developed for rapid measurement of large plant populations, while LeasyScan supported efficient assessment of plant growth and leaf-related traits. These systems demonstrate how automation can reduce the time and labour required to collect reliable phenotypic information has developed high-throughput phenotyping capabilities within the ICAR system and partner research institutions. Research programmes increasingly combine imaging, drones, remote sensing, artificial intelligence, and precision agriculture. The Nanaji Deshmukh Plant Phenomics Centre at ICAR-IARI is an important example of infrastructure.

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Challenges and practical solutions

High cost of advanced sensors: Advanced hyperspectral and thermal systems can be expensive.

Solution: Shared research facilities, drones and targeted sensing can reduce the cost of data collection. Collaborative use of high-end equipment among universities, research institutes and farmer groups can improve affordability. Low-cost RGB cameras, smartphones and open-source sensors can also be used for basic phenotyping applications.

Large and inconsistent datasets: Different researchers may use different protocols and trait definitions.

Solution: Common standards, metadata and interoperable databases are essential. Standardized data collection protocols can improve the comparability and reliability of phenomic datasets.

AI model reliability: A model trained at one location may not work equally well in another.

Solution: Models should be validated across different varieties, seasons, climates and locations. Regular updating and retraining with diverse datasets can improve model robustness and prediction accuracy. Independent field validation is also necessary before using AI-based recommendations for large-scale crop management.

Small and fragmented farms: Many Indian farms are small and fragmented, making sophisticated technology difficult for individual farmers at ground level because most are small and marginal landholder farmers.

Solution: Phenomic information can be delivered through extension services, custom-hiring centres and simple mobile decision-support systems. Farmer producer organizations and cooperative groups can facilitate collective access to drones, sensors and phenotyping services. User-friendly mobile applications can translate complex phenomic data into simple recommendations for farmer.

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