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Post-independence agricultural growth in India: a crop physiology perspective

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Abstract

After independence, Indian agriculture has undergone a remarkable transformation from food scarce to self-sufficiency and one of the largest food exporting countries in the world. This journey was successful due to both technological and scientific interventions in the agriculture. In this journey, crop physiology has played a hidden role in shaping India's agriculture. Crop physiology is branch of science that deals with how plants function and responds to varying environmental conditions. Understanding the physiological processes such as photosynthesis, transpiration, nutrient uptake, and stress responses has enabled scientists and farmers to improve crop yields, develop climate-resilient varieties, and enhance the efficient use of water and nutrients. It has now formed the foundation of climate-resilient agriculture, utilizing methods such as CRISPR, AI-based crop modelling, and precision farming.

Introduction

Preliminary developments (1947-1960's)

After independence, Crop physiology was in its formative phase. Initially, scientific research was more focussed on understanding the physiological processes such as photosynthesis, respiration transpiration and nutrient uptake. These foundational studies helped in understanding the influence of various environmental factors such as temperature, light, water and soil fertility on crop growth and yield. Though this early research did not directly result in yield advances, they did lay the framework for future advancements by assisting scientists and breeders in understanding how crops interact with their surroundings.

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Physiological innovations for high yields during green revolution era (1960s – 1970s)

The green revolution, which began in India during 1960's marked as a transformative period in the country's agricultural history. While, the noticeable aspects of this revolution were widespread adoption of high yielding varieties (HYVs) of rice and wheat, chemical fertilizers and irrigation (Singla and Sharma, 2021). Crop physiologists played a critical role in obtaining and maintaining these high yield levels. One of the outstanding and remarkable contribution of crop physiologists was improvement of harvest index- ratio of economic yield to plants total biomass. Most of the traditional Indian varieties exhibited high vegetative growth and low yields. Large proportion of assimilates were going to developing leaves and stem (non-edible parts) rather than edible parts. In addition to this, traditional tall crop varieties have tendency to lodge when exposed to heavy rains, winds or heavy grain load. Physiological research played a prominent role in resolving this issue by investigating the structural and hormonal variables that lead to plant lodging. They observed that stem strength, especially the diameter and thickness of culms (stems), was critical in providing the mechanical support required to hold heavy grain heads. They also investigated the role of plant hormones, especially gibberellins, in regulating stem elongation. Gibberellins stimulated excessive vertical development in tall traditional varieties, resulting in longer stems that were weaker and more prone to bending or breaking.

Physiological study found that to increase yield, it was critical to breed varieties with compact, controlled growth and the ability to allocate more photosynthates to grain development, during the reproductive phases. At the same time, it was critical to maintain enough vegetative growth to enable photosynthesis and grain filling while avoiding excessive leaf or stem growth, which would waste resources. These findings paved the way for the development and adoption of semi-dwarf varieties with shorter stature and efficient nutrient absorption and were better in channelling the energy towards grain production. Physiologists collaborated with breeders to develop semi-dwarf varieties that were less susceptible to gibberellins. Because of the hormonal resistance, the plants produced shorter stems while maintaining adequate vegetative growth for optimal development. These compact, sturdy plants possessed thicker stems and a lower centre of gravity, making them far more resistant to lodging, even when cultivated with high nitrogen fertilizers. Fertilizers normally stimulate lush growth, which can exacerbate lodging in tall variety, but the new semi-dwarf species can efficiently use large inputs without collapsing. Lodging resistance was more than just a desirable characteristic; it was a game changer that enabled modern, high-input agriculture in India and other emerging countries. In addition to this, efficient nutrient absorption enabled the farmers to apply the more fertilizers with confidence knowing that the crop would be able to withstand resulting biomass gain and efficiently convert it into yield. This physiological advantage made them significantly more productive and ideal for high-input agriculture, which served as the foundation for the Green Revolution. Moreover, understanding the crop phenology helped in development of varieties that mature faster so that they can avoid critical stress periods such as terminal drought or high temperature, especially in wheat.

Restructuring phase (1970s-1985s)

Focus in crop physiology shifted from maximizing yields to stabilizing productivity. One of the main areas of research was canopy structure and light interception, with the goal of optimizing plant architecture for increased photosynthetic efficiency. Many of the short duration pulse and oil seed varieties, which fit into multiple and intercropping systems were developed. Investigation on how crops absorbed water and nutrients led to improved irrigation and fertilization practices during this phase (Ren et al., 2023).

Post green revolution – sustainability phase (1985s-2000)

During this time, the National Agricultural Research Project (NARP), launched by ICAR, broadened its scope to solve regional agricultural concerns by bolstering state agricultural institutions and research stations. This decentralization enabled tailored physiological investigations based on local crop kinds, soil characteristics, and weather circumstances. Researchers began focusing on abiotic stresses such drought, salinity, and heat stress, which hampered productivity in many rainfed and marginal locations. Physiologists studied how crops responded to these stresses at the cellular and whole-plant levels, which led to the identification of stress-tolerant traits such as osmotic adjustment, stomatal regulation, and deep root systems. Understanding these pathways laid the foundation for developing climate-resistant cultivars. This period also witnessed a push for agricultural diversification, as the Green Revolution's monoculture of rice and wheat caused soil degradation and reduced biodiversity. Physiological research supported the promotion of underutilized but climate-resilient crops such as pulses, oilseeds, and coarse cereals, which are well adapted to dryland farming systems.

Modern Crop Physiology Era (2000s-present)

In the early 2000s, rapid advances in molecular biology and functional genomics opened up new avenues for studying how plants respond to environmental stimuli at the genetic and biochemical levels. Researchers began to identify and characterize genes involved in photosynthesis, drought tolerance, salt stress, and nutrient intake. This increased understanding enabled researchers to target certain physiological features in breeding programs.

Another achievement during this time was the development of climate-resistant varieties. These were bred to perform better in adverse environments such as irregular rainfall, high temperatures, and degraded soils. Physiological screening for features such root depth, leaf temperature regulation, canopy architecture, and transpiration efficiency became common practice when evaluating new cultivars. Remote sensing, GIS, and crop phenotyping platforms were introduced concurrently to investigate large-scale crop activity. These technologies enabled the monitoring of physiological responses such as chlorophyll content, canopy temperature, and water stress in a variety of conditions, hence improving breeding and farm management decisions.

The National Initiative on Climate Resilient Agriculture (NICRA) launched by ICAR in 2010 was an important moment in Indian agricultural research since it formalized the integration of crop physiology into the national climate adaptation plan. NICRA aimed to create and implement climate-resilient technologies for crops, livestock, and natural resource management, with a particular emphasis on studying and enhancing crop responses to climatic stresses. It prioritized on-farm research to evaluate crop behaviour in drought, heat, and flood conditions, employing physiological methods to uncover essential adaptation features such as early maturity, heat tolerance, and submergence resistance. These discoveries influenced the creation and widespread adoption of climate-resilient rice, wheat, maize, and millets. Crop physiology has developed from a merely academic discipline to a crucial driver of national policy and field-level resilience, influencing India's agricultural response to climate change (Burman *et al.,* 2017)

Crop physiology research improved between the 2010s and the 2020s, with a focus on improving nutrient efficiency, sustainability, and precision agriculture. Carbon use efficiency (CUE) focuses on how efficiently plants convert carbon into biomass, while water productivity focuses on features such as stomatal regulation and water use efficiency (WUE) to improve yield per unit of water. Furthermore, nutritional physiology played an important role in biofortification, resulting in crops enriched with micronutrients such as zinc, iron, and vitamin A. This period also witnessed the use of CRISPR and gene-editing techniques to fine-tune physiological features such as drought tolerance and nutrient metabolism, resulting in more precise and efficient crop development.

Crop physiology has emerged as a critical component of smart agriculture since 2020, owing to the integration of digital technologies and the demand for climate-sensitive, sustainable farming. Advanced techniques, such as AI-based crop modelling, now employ physiological data to predict crop performance under various climatic and management situations, allowing for more precise and proactive decision-making. On the ground, sensors and IoT devices monitor real-time plant characteristics including as soil moisture, canopy temperature, and chlorophyll content, enabling for more precise irrigation and nutrient management interventions.

Conclusion

Since, independence, crop physiology played a significant role in transforming India's agriculture. Initially, physiological research contributed to the success of the Green Revolution by understanding of crop development, nutrient uptake, and yield potential under Indian agro-climatic conditions. In succeeding decades, the emphasis switched to stress physiology, which helped to address issues such as drought, salinity, and nutrient scarcity through improved crop variety and

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resource management. In the present period, it has been integrated with digital tools, artificial intelligence, and precision farming, resulting in smarter, more efficient, and environmentally friendly agriculture. Overall, crop physiology has increased productivity while also ensuring long-term agricultural stability and resilience, making it an important driver of India's agricultural success story.

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