



Pioneering the Green Genome: Prof. Chittaranjan Kole's Enduring Impact on Biodiversity, Crop Genetics and Sustainable Food Security

Achyuta Basak¹
Victor Sarkar²

¹Division of Genetics
ICAR-Indian Agricultural
Research Institute, Pusa
New Delhi-110012

²Malda Krishi Vigyan Kendra
Uttar Banga Krishi
Viswavidyalaya, Ratua, Malda
West Bengal, India- 732205



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*Corresponding Author

Achyuta Basak*

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INTRODUCTION

Twenty-first-century agricultural sciences are confronted with the daunting challenge of resolving one of mankind's most complex problems: boosting food productivity by around 70% to feed an expected world population of 9.7 billion people in 2050, while at the same time enabling crops to adapt to increasingly unpredictable climates (Mahalik & Guru, 2023).

Conventional crop breeding methods, which relied heavily on phenotypic selection across prolonged field generations, are constrained by time and limited genetic variation in elite germplasm (Ramchiary & Kole, 2019). The fulfillment of global aspirations concerning food, nutrition, and environmental security requires a rapid move towards genomics-enabled precision breeding, allele mining, and biotechnology (Kole, 2020). Among the global scientific community, Prof. Chittaranjan Kole stands out as a pioneering figure who helped shape this transition. Over a professional career spanning more than four decades, Prof. Kole has made fundamental contributions to plant structural and functional genomics, molecular cytogenetics, crop biotechnology, and biodiversity utilization (Nageswara-Rao *et al.*, 2026). These contributions include the pioneering physical mapping and sequencing of a plant gene by an Indian scientist and the concept of "genomic designing" of climate-smart crops (Kole, 2020). Apart from research work, his administrative roles in Indian and international organizations, as well as his editorial responsibilities for basic multivolume scientific literature, have played an important role in developing global standards for crop genome dissection (Kole *et al.*, 2023).

Academic Trajectory and Global Institutional Leadership:

Prof. Chittaranjan Kole's scientific journey is marked by administrative leadership, cross-border research coordination, and international academic collaboration. In India, he served in high academic positions, notably as the Vice-Chancellor of Bidhan Chandra Krishi Viswavidyalaya (BCKV) in West Bengal, where he spearheaded reforms in agricultural education, postgraduate research, and institutional infrastructure. As the Project Coordinator of the Indo-Russian Center of Biotechnology, he initiated and coordinated research activities that aimed at applying molecular biology in improving crops and developing industrial biotechnological products (Kole *et al.*, 2023).

Prof. Kole's expertise led to appointments across leading global research institutions. In the United States, he served as a Visiting Professor at Pennsylvania State University and Clemson University, subsequently assuming the role of Director of Research at the Institute of Nutraceutical Research at Clemson University (Kole *et al.*, 2023). Once back in India, he received the prestigious Raja Ramanna Fellowship from the Department of Atomic Energy (DAE), Government of India, and he got involved in advanced genomic research in the ICAR-National Institute for Plant Biotechnology (NIPB) (earlier NRCPB) in New Delhi (Ramchiary & Kole, 2019).

Prof. Kole's achievements have earned him formal recognition across the international scientific community. His research and editorial contributions have been commended by seven Nobel Laureates namely Prof. Norman Borlaug, Arthur Kornberg, Werner Arber, Phillip Sharp, Günter Blobel, Lee Hartwell, and Roger Kornberg, as well as eminent World Food Prize Laureates including Prof. M.S. Swaminathan and Prof. G.S. Khush. He has received numerous awards, such as the Outstanding Crop Scientist Award from the International Crop Science Society, the Hind

Rattan (Jewel of India) Award, the Dr. Sadgopal Memorial Award, and the Crop Research Award (Agri Vision, 2025). Also, his academic achievements have helped him become an honorary member of the Indian Society of Genetics and Plant Breeding (ISGPB), the Indian Academy of Social Sciences, the Uttar Pradesh Academy of Agricultural Sciences, the Bioved Research Institute, and the Henan Academy of Agricultural Sciences in China.

Scientific Achievements in Genomics and Biotechnology

Gene Isolation and Early Molecular Cytogenetics

During the early stages of plant molecular biology, Prof. Kole achieved a notable milestone by becoming the first Indian scientist to physically map and sequence a plant gene, specifically within barley (*Hordeum vulgare*) (Nageswara-Rao *et al.*, 2026). This discovery helped demonstrate the feasibility of reading the chemical genetic code of crop plants directly, providing a foundation for modern structural genomics (Ramchiary & Kole, 2019). His early work on repetitive DNA organization and 5S-rRNA genes in major cereals introduced the concept of "genomic dactyloscopy". By employing restriction enzyme digestion coupled with Southern blot hybridization, Prof. Kole showed that repetitive DNA patterns produce species-specific restriction profiles. These profiles served as molecular signatures to identify crop species, establish chromosomal localizations, and provide early molecular evidence regarding comparative evolutionary relationships across cereal genomes (Nageswara-Rao *et al.*, 2026).

Molecular Mapping and Gene Discovery in Brassica Crops

His most significant research works have been in the field of genomics and molecular breeding of oilseed and vegetable *Brassica* species. The importance of *Brassica* crops like Indian mustard (*Brassica juncea*), rapeseed (*Brassica napus*), and turnip rape (*Brassica rapa*) lies in

their significance as a source of edible oil and vegetable protein. However, their cultivation often faces obstacles in the form of diseases caused by fungi like white rust (*Albugo candida*) and extreme environmental conditions.

To address these production barriers, Prof. Kole constructed molecular linkage maps using Restriction Fragment Length Polymorphism (RFLP) and Random Amplified Polymorphic DNA (RAPD) markers. A key methodology developed in his lab was the "Mendelization" of Quantitative Trait Loci (QTLs)—a process that dissects complex polygenic traits governed by multiple genes into discrete, single-gene Mendelian factors using Recombinant Inbred Lines (RILs). This approach allowed his team to map and tag major resistance loci against white rust. Specifically, he mapped the primary white rust resistance gene, *Aca1*, onto linkage group BR4

in *Brassica rapa*. Through comparative genome mapping, he established that BR4 shares syntenic homology with the *BN19* and *BN9* chromosomes of *Brassica napus*, establishing a structural framework for transferring resistance traits across amphidiploid *Brassica* species. Also, Prof. Kole conducted comparative mapping studies linking *Brassica* genomes with the model plant *Arabidopsis thaliana*. His work demonstrated the evolutionary conservation between the *VFR2* (Vernalization Flowering Response 2) locus in *Brassica rapa* and the *FLC* (FLOWERING LOCUS C) gene in *Arabidopsis*, shedding light on the molecular mechanisms controlling flowering time and winter hardiness. In *Brassica juncea*, his team identified RAPD markers linked to QTLs controlling oleic acid levels, establishing early marker-assisted selection (MAS) tools for breeding mustard lines with healthier fatty acid profiles (table 1)

Table 1: Landmark Gene Discoveries, Molecular Markers, and Breeding Impacts in Cereal and *Brassica* Crops (Nageswara-Rao *et al.*, 2026)

Trait / Biological Target	Crop / Organism	Primary Genetic Loci / Markers	Agricultural & Biotechnological Impact
Physical Mapping & Sequencing	Barley (<i>Hordeum vulgare</i>)	Physical DNA sequence	Pioneer achievement establishing physical gene isolation in cereals.
Genomic Dactyloscopy	Cereal species	5S-rRNA, repetitive DNA loci	Generated molecular profiles for species identification and comparative cytogenetics.
White Rust (<i>Albugo candida</i>) Resistance	<i>Brassica rapa</i> , <i>Brassica napus</i>	<i>Aca1</i> locus (Linkage Group BR4 / BN19, BN9)	Enabled marker-assisted selection for resistance against pathotypes AC2 and AC7.
Flowering Time & Vernalization	<i>Brassica rapa</i> , <i>Arabidopsis thaliana</i>	<i>VFR2</i> locus (syntenic to <i>Arabidopsis FLC</i>)	Elucidated evolutionary mechanisms governing flowering time and climate adaptation.
Oleic Acid Quality Improvement	<i>Brassica juncea</i> (Mustard)	RAPD-derived QTLs	Facilitated molecular breeding for modified fatty acid compositions in edible oil.

Spearheading Climate-Smart Agriculture and Genomic Designing

Increased difficulties caused by the impact of global warming such as increased temperatures, drought occurrences, soil salinity, and development of pests' pressures are serious

threats to agricultural production across the globe. Recognizing the fact that traditional breeding techniques are not always sufficient for following the changing climatic conditions, Prof. Kole introduced the idea of Genomic Designing of Climate-Smart Crops (Kole,

2020). This framework shifts agricultural breeding from passive selection toward proactive, sequence-based crop architecture.

In order to apply this principle worldwide, Prof. Kole founded the International Climate-Resilient Crop Genomics Consortium (ICRCGC) (Springer, n.d.) and became its first President. ICRCGC brings together plant geneticists, biotechnologists, computational biologists, and climate scientists from various continents. The goal of the consortium is to use whole genome sequencing (WGS), multi-omics technologies, and high-throughput phenotyping to reveal functional genes and sequence variants that are responsible for abiotic and biotic stress tolerance, yield stability under various environmental conditions.

A core pillar of Prof. Kole's climate strategy is allele mining (Kole *et al.*, 2023). While elite crop varieties often lack sufficient genetic diversity due to historical breeding bottlenecks, unadopted landraces, wild progenitors, and genebank accessions harbour vast reserves of stress-adaptive alleles. Through allele mining, scientists can systematically scan genebank collections to identify superior variants of functional genes. Using marker-assisted introgressions, gene pyramiding, and genomic selection (GS), these valuable alleles can be incorporated into high-yielding crop backgrounds without transferring undesirable wild traits (Kole *et al.*, 2023). Through his edited reference books covering cereals, pulses, oilseeds, vegetables, and fruits, Prof. Kole helped establish standard workflows for genomic designing, providing plant breeders worldwide with strategies to build climate-resilient crop varieties.

Biodiversity Conservation and Nutriomics

Agricultural biodiversity provides the genetic foundation necessary for future crop adaptation and food security. However, millions of

germplasm accessions stored in global genebanks remain underutilized because they lack systematic molecular and phenotypic characterization. Prof. Kole has long advocated for the comprehensive characterization and preservation of biodiversity using modern genomic technologies.

To promote genomic research and biodiversity utilization in India, Prof. Kole founded Genome India International (GII), serving as its Founding President. GII serves as a platform to coordinate national plant genomic projects, facilitate inter-institutional research, and align Indian crop sequencing initiatives with international standards. Simultaneously, Prof. Kole expanded the scope of plant genomics beyond agronomic yield to encompass human nutrition and health. He founded and leads the International Phytomedomics and Nutriomics Consortium (IPNC) as its Founding President. The IPNC integrates "phytomedomics"—the genomic mapping of plant medicinal compounds—with "nutriomics," the structural and functional analysis of plant nutritional profiles. This approach supports biofortification initiatives aimed at combating "hidden hunger" or micronutrient deficiencies. By identifying genes regulating the biosynthesis and accumulation of essential vitamins, iron, zinc, carotenoids, and health-promoting phytochemicals in staple and underutilized crops, the IPNC provides a roadmap for breeding nutrient-dense crops (Kole, 2023).

To ensure that scientific advancements benefit farming communities and broader society, he established the Prof. Chittaranjan Kole Foundation for Science and Society, serving as its Founding Chairman. The foundation focuses on science communication, supporting young researchers, and bridging high-tech biotechnology with practical agricultural applications.

Table 2: Strategic Platforms Established by Prof. Chittaranjan Kole for Climate Resilience, Nutriomics, and Societal Outreach

Consortium / Platform	Leadership Role	Focus Area & Strategic Objectives
International Climate-Resilient Crop Genomics Consortium (ICRCGC)	Founding President	Mobilizes global genomic resources to design crops resilient to extreme weather, drought, heat, and disease.
Genome India International (GII)	Founding President	Coordinates national and international plant genome sequencing, biobanking, and computational pipelines.
International Phytomedomics & Nutriomics Consortium (IPNC)	Founding President	Integrates genomics with plant nutrition and medicinal profiling to accelerate crop biofortification.
Prof. Chittaranjan Kole Foundation for Science and Society	Founding Chairman	Promotes scientific literacy, mentors early-career researchers, and connects biotechnology with social welfare.

Global Editorial Acumen and Scientific Publications

Prof. Kole's impact on global agriculture is further reflected in his scientific publications and editorial leadership. He has published more than 150 peer-reviewed research papers and reviews in international journals. However, his most widespread contribution to plant science education lies in his work as an editor for major academic publishers, including Springer, CRC Press / Taylor & Francis Group, and Wiley-Blackwell. Recognizing that rapid advancements in whole-genome sequencing were generating vast amounts of data scattered across disparate journals and specialized databases, Prof. Kole worked to synthesize this information into structured reference books. His multivolume book series serve as comprehensive references for researchers, professors, and plant breeders globally.

The seven-volume series *Genome Mapping and Molecular Breeding in Plants*, published by Springer, covers 82 economic crop species across cereals, oilseeds, pulses, fruits, vegetables, technical crops, and forest trees (Kole, 2007). This series provided a consolidated overview of genetic linkage maps, cloned genes, and marker-assisted selection protocols. Following this, Prof. Kole edited the *Compendium of Plant Genomes* series for Springer, featuring individual volumes

dedicated to the whole-genome sequencing, structural annotation, and comparative genomics of individual crops such as pepper (*Capsicum*), mango, jute, and bitter gourd (Ramchiary & Kole, 2019).

To address climate adaptation, he conceptualized and edited the *Genomic Designing of Climate-Smart Crops* series, providing target gene lists, allele sources, and molecular breeding blueprints across major food crops. His series *Allele Mining for Genomic Designing* provided practical protocols for Eco-TILLING, PCR-based priming, and bioinformatic screening to discover novel alleles in wild germplasm. In addition, the *Compendium of Crop Genome Designing for Nutraceuticals* detailed molecular strategies to enhance micronutrient density, secondary metabolites, and pharmaceutical compounds in horticultural and field crops (Kole, 2023).

CONCLUSION

Prof. Chittaranjan Kole's career illustrates how basic scientific discovery can be integrated with applied crop improvement to address pressing global and national challenges. Regarded as the "*Father of Plant Genomics in India*", the "*Father of Plant Biotechnology in India*", and the "*Father of Agri-Nanotechnology in the World*", his landmark contributions ranging

from early gene mapping in barley and key discoveries in *Brassica* genetics to founding global climate consortia and editing foundational reference works have left an indelible mark on agricultural science. By establishing frameworks for genomic designing, allele mining, and phytomedomics, Prof. Kole has provided modern plant breeders with essential tools to harness agricultural biodiversity. At a pivotal moment for Indian farming, his work is defining what sustainable, future-ready food systems should look like. His pioneering vision of climate-resilient, nutrient-rich crops continues to inspire and guide researchers, progressive farmers, and policymakers working to safeguard the future of farming.

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