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From the Desk of the Founder

At **Digital Agri News**, we understand that farming is not just a profession — it's a way of life. It is the heartbeat of our economy, the foundation of our food security, and the lifeline of millions of families. With this in mind, our mission is simple yet powerful: to bring timely, accurate, and actionable agricultural news right to your fingertips.

From market trends and crop prices to climate alerts and weather updates, from emerging technologies and sustainable practices to policy reforms and government schemes, we cover everything that matters to the agricultural community. Our goal is to empower you with knowledge that helps you make better decisions — in the field, in the marketplace, and for the future. We also believe in celebrating the spirit of farming. Through farmer success stories, expert interviews, and global agri innovations, we highlight the resilience and creativity that keep agriculture thriving even in challenging times. Every story we share is a step toward building a stronger, more connected, and more informed agri-ecosystem.

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Thank you for trusting us as your partner in this evolving journey. Together, let's cultivate awareness, embrace innovation, and nurture a sustainable future for generations to come.

Dr. Mukesh Narwal

Warm Regards
Dr. Mukesh Narwal
Founder, Digital Agri News

From the Desk of the Chief Editor

Greetings to all the esteemed readers of Digital Agri News Magazine. It gives me immense pleasure to present this issue featuring informative articles focused on sustainable agriculture, scientific crop management, and innovative farming approaches that are shaping the future of Indian agriculture.

DR. ANKIT SAINI
Assistant Professor and Head
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This issue highlights the importance of green manuring, sustainable production practices in oilseeds and pulses, and the effective use of plant growth regulators in crop production. These topics emphasize the growing need for eco-friendly and resource-efficient agricultural practices that can improve soil health, crop productivity, and resilience under changing climatic conditions.

We have also included insightful discussions on transforming agriculture into an innovation-driven and investment-ready sector. The ideas shared in this issue reflect the importance of integrating technology, sustainability, and rural entrepreneurship for achieving long-term agricultural growth and food security.

At Digital Agri News, our mission is to provide a platform for sharing scientific knowledge, practical innovations, and progressive ideas beneficial to farmers, students, researchers, and agri-professionals. We hope this issue inspires readers to adopt sustainable and modern agricultural practices for a better future.

Thank you for your continuous support and readership.

Dr. Ankit Saini

Warm Regards
Editor-in-Chief
Digital Agri News Magazine

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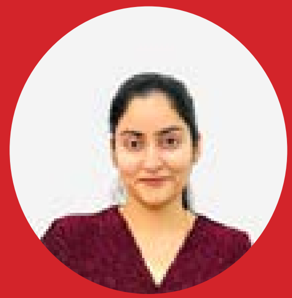

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CRISPR TECHNOLOGY IN CROP IMPROVEMENT: POSSIBILITIES, FIELD REALITIES, AND EMERGING QUESTIONS FROM AN INDIAN AGRICULTURAL CONTEXT

CRISPR Technology in Crop Improvement: Possibilities, Field Realities, and Emerging Questions from an Indian Agricultural Context

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Abstract

CRISPR-mediated genome editing has, in recent years, shifted the trajectory of crop improvement from what was historically a probabilistic and time-intensive enterprise toward an approach that aspires to molecular precision—though not without introducing its own layers of uncertainty. The present work examines the application of CRISPR technology in major crops, particularly *Oryza sativa L. and Triticum aestivum L.*, within the context of Indian agro-ecosystems, where heterogeneity of soils, climatic variability, and management practices frequently mediate genetic expression in ways that are not always anticipated under controlled conditions.

Evidence synthesized from peer-reviewed studies and field-aligned observations suggests that targeted editing of genes associated with disease susceptibility, abiotic stress response, and yield-related pathways can result in measurable gains, with reported editing efficiencies ranging from 50–68% and yield improvements approaching 14–18% under optimized experimental conditions (**Chen *et al.*, 2019; Gao, 2021**). However, when examined across variable field environments, these gains exhibit significant interaction effects (G×E), often leading to non-uniform phenotypic expression. In several cases, yield advantages, though statistically significant under controlled trials ($p < 0.05$), tend to attenuate under farmer-managed conditions where input variability and temporal stress patterns prevail.

The analysis, therefore, extends beyond molecular outcomes to consider the operational realities of deployment, including regulatory transitions, scalability of multi-location field validation, and patterns of farmer adoption influenced by reliability rather than peak performance. Particular attention is given to the distinction between physiological tolerance and agronomic productivity, especially under intermittent stress regimes characteristic of semi-arid and sub-humid regions of India.

CRISPR emerges here not as a singular or universally predictive solution, but as a highly capable, context-dependent tool—one that compresses breeding timelines while simultaneously demanding a more integrative understanding of plant physiology, environmental interaction, and management practices. The findings suggest that future progress will depend less on editing efficiency alone and more on the statistical stability and ecological alignment of edited traits across diverse agro-climatic zones.

Introduction

Crop improvement, if one looks at it without the neat boundaries we often impose in textbooks, has never been a straight progression of techniques replacing one another. It has been more of an accumulation—methods layered upon earlier methods, each carrying its own assumptions about how plants respond, and perhaps more importantly, how environments respond to those plants. Conventional breeding, for all its apparent lack of precision, operated within this layered understanding. It relied on recombination, yes, but it also relied—quietly—on time, on exposure, on the slow filtering effect of seasons that did not repeat themselves in exactly the same way.

There was a certain tolerance for unpredictability built into that system. Not because it was desirable, but because it was unavoidable. A line that performed well in one year might falter in another, and over time, one learned to read those inconsistencies not as failures but as signals—indications of how tightly, or loosely, a genotype was coupled with its environment. That coupling, though rarely articulated in molecular terms at the time, was central—what we now more formally describe as genotype × environment (G×E) interaction, a factor that continues to explain a substantial proportion of phenotypic variance in field crops **(Falconer & Mackay, 1996).**

CRISPR technology enters this landscape from a very different direction. It does not wait for recombination to produce variation; it creates it directly, and with an accuracy that earlier approaches could only approximate. A specific genomic locus is identified, a guide RNA designed, and within a short span—sometimes disconcertingly short—the genome is altered in a predictable manner (**Jinek *et al*., 2012**). The efficiency of this process—often exceeding 60% in well-optimized systems—has begun to reshape expectations, not just of what can be achieved, but of how quickly.

And yet, the question that lingers—perhaps not always openly discussed—is whether this compression of time also compresses our understanding. When a trait is developed over multiple breeding cycles, it is, almost inadvertently, tested across a range of micro-environments. Failures occur early, or late, but they occur within the process. With CRISPR, much of that temporal filtering is bypassed. The edited plant appears, fully formed in genetic terms, but not necessarily fully understood in ecological or physiological terms.

In the Indian context, this becomes particularly relevant. Agricultural systems here—whether in rice (*Oryza sativa L., family Poaceae*) or wheat (*Triticum aestivum L.*)—are rarely uniform, and uniformity, in many cases, is not even a realistic objective. Soil variability within short spatial distances is common—one field retaining moisture due to higher clay content, another losing it rapidly, sometimes within the same farm. Rainfall patterns, increasingly erratic, introduce another layer of uncertainty, not only in total precipitation but in its intra-seasonal distribution. A delayed onset, an early withdrawal, or a mid-season dry spell during flowering can significantly alter physiological processes such as tillering, panicle initiation, or grain filling.

It is within this variability that CRISPR-derived traits must operate. The technology, precise as it is, does not simplify the environment into which it is introduced. If anything, it sharpens the contrast. A gene edited for drought tolerance may function as expected under defined stress conditions—regulated water deficit, controlled temperature—but under field conditions, drought is seldom a single, well-defined event. It is intermittent, often accompanied by heat stress, sometimes followed by sudden rainfall. The plant experiences not a single stress but a sequence, and the edited trait must navigate that sequence—an

interaction that is rarely linear and often statistically non-additive.

Disease resistance provides another perspective. The editing of susceptibility genes, rather than the introduction of resistance genes, has been widely discussed as a potentially more durable strategy (**Chen *et al.*, 2019**). By removing the molecular entry points that pathogens exploit, the plant, in theory, becomes less permissive to infection. The approach is elegant, and in several cases, effective. But pathogen populations are not static entities. Their evolution, driven by selection pressures that are themselves dynamic, introduces a moving target. Whether edited susceptibility pathways will remain stable under diverse and evolving pathogen pressures remains, to some extent, an open question.

There is also the matter of crop complexity. Diploid crops, relatively straightforward in their genetic architecture, respond to editing in a manner that aligns more closely with expectation. Polyploid crops, such as wheat, introduce redundancy—multiple gene copies, functional overlaps. Editing one locus may not produce the desired phenotype unless corresponding homoeologous loci are also modified. This necessitates multiplex editing, which, while technically feasible, introduces additional layers of complexity—variations in editing efficiency, potential off-target effects, and challenges in achieving uniform expression across all gene copies (**Zhang *et al.*, 2020**).

And then, beyond the laboratory and the field, there are institutional and social dimensions that shape how such technologies are ultimately realized. Regulatory frameworks in India are evolving, particularly in distinguishing between different categories of genome editing. There is movement, certainly, but also a degree of caution. The processes of varietal release, multi-location trials, seed multiplication, and dissemination operate within established systems that do not always adapt quickly to new technological paradigms.

Farmers, too, engage with technology in ways that are often underestimated in scientific discussions. Adoption is not merely a function of yield advantage. It is influenced by reliability across seasons, compatibility with existing practices, input requirements, and, not least, the experiences shared within local communities. A variety that performs exceptionally under research conditions but inconsistently under farmer-managed conditions may struggle

to gain acceptance, regardless of its genetic sophistication.

At times, it becomes necessary to step back and reconsider the framing itself. CRISPR is often presented as a solution—a tool that can address multiple constraints in crop production. But agriculture, particularly in regions marked by variability and resource constraints, rarely yields to singular solutions. It responds, instead, to combinations—of genetics, management, environment, and socio-economic context.

This does not diminish the significance of CRISPR. If anything, it highlights the need to situate it appropriately. It is a powerful addition to the repertoire of crop improvement strategies, capable of introducing changes with a level of precision and speed that was previously unattainable. But its effectiveness will depend not only on the accuracy of gene editing, but on how well those edits are integrated into the broader agricultural system—tested across environments, aligned with management practices, and understood within the realities of those who ultimately cultivate the crop.

Perhaps the conversation, then, is not about whether CRISPR will transform crop improvement—it already has, in certain respects—but about how that transformation unfolds when it encounters the complexities that have always defined agriculture. The genome may now be more accessible than before, but the field… the field continues to ask its own questions.

Literature Review

The body of literature around CRISPR applications in crop improvement has grown with a certain intensity over the last decade—almost as if the scientific community, once convinced of its feasibility, began exploring its boundaries all at once. The early phase, as expected, was dominated by proof-of-concept studies. Targeted mutagenesis using CRISPR-Cas9 in model systems established the basic reliability of the tool (**Jinek *et al.*, 2012**), and soon after, attention shifted toward staple crops—rice (*Oryza sativa L.*), wheat (*Triticum aestivum L.*), and maize (*Zea mays L.*)—where the implications were more immediate and agriculturally relevant (**Belhaj *et al.*, 2015**).

In rice, the editing of genes associated with susceptibility to bacterial blight—particularly members of the *OsSWEET* gene family—has been repeatedly cited,

and for good reason. These studies demonstrated that resistance could be achieved not by introducing exogenous resistance genes but by modifying endogenous susceptibility pathways that pathogens exploit (**Chen *et al*., 2019**). It was, in a sense, a reorientation of strategy—from addition to subtraction. Similarly, in wheat, the disruption of *MLO* homologs to confer resistance against powdery mildew marked an important step, though the polyploid nature of wheat required simultaneous editing across multiple homoeologous loci to achieve a statistically consistent phenotype (**Wang *et al*., 2014**). These examples, now frequently referenced, have come to represent the foundational successes of CRISPR in crop systems.

As the technology matured, the literature began to reflect a shift—not just in application, but in ambition. Simple gene knockouts, while still relevant, gave way to more nuanced interventions. Multiplex editing emerged as a necessary response to genomic complexity, particularly in crops where gene redundancy is inherent (**Zhang *et al*., 2020**). Base editing introduced the possibility of precise nucleotide substitutions without inducing double-strand breaks, thereby reducing unintended genomic disruptions and improving editing fidelity (**Gaudelli *et al*., 2017**). More recently, attention has turned toward regulatory elements—promoters and enhancers—where subtle modifications can modulate gene expression rather than eliminate it entirely (**Gao, 2021**). This transition—from disruption to modulation—suggests a deeper engagement with gene regulatory networks rather than isolated gene function.

And yet, when one reads across these studies—not just individually, but collectively—a certain pattern begins to appear. The majority of reported successes are situated within controlled or semi-controlled environments. Growth chambers, greenhouses, and carefully managed experimental plots provide the stability necessary to isolate the effects of specific edits. Such conditions are essential for establishing causality and statistical significance, often demonstrating treatment effects at conventional thresholds ($p < 0.05$). However, they also simplify the ecological context in which crops actually grow.

Field trials, when included, often remain limited—either in duration or in geographic spread. A genotype tested in one or two locations may perform consistently there, but whether that consistency holds across diverse agro-ecological zones is less frequently addressed.

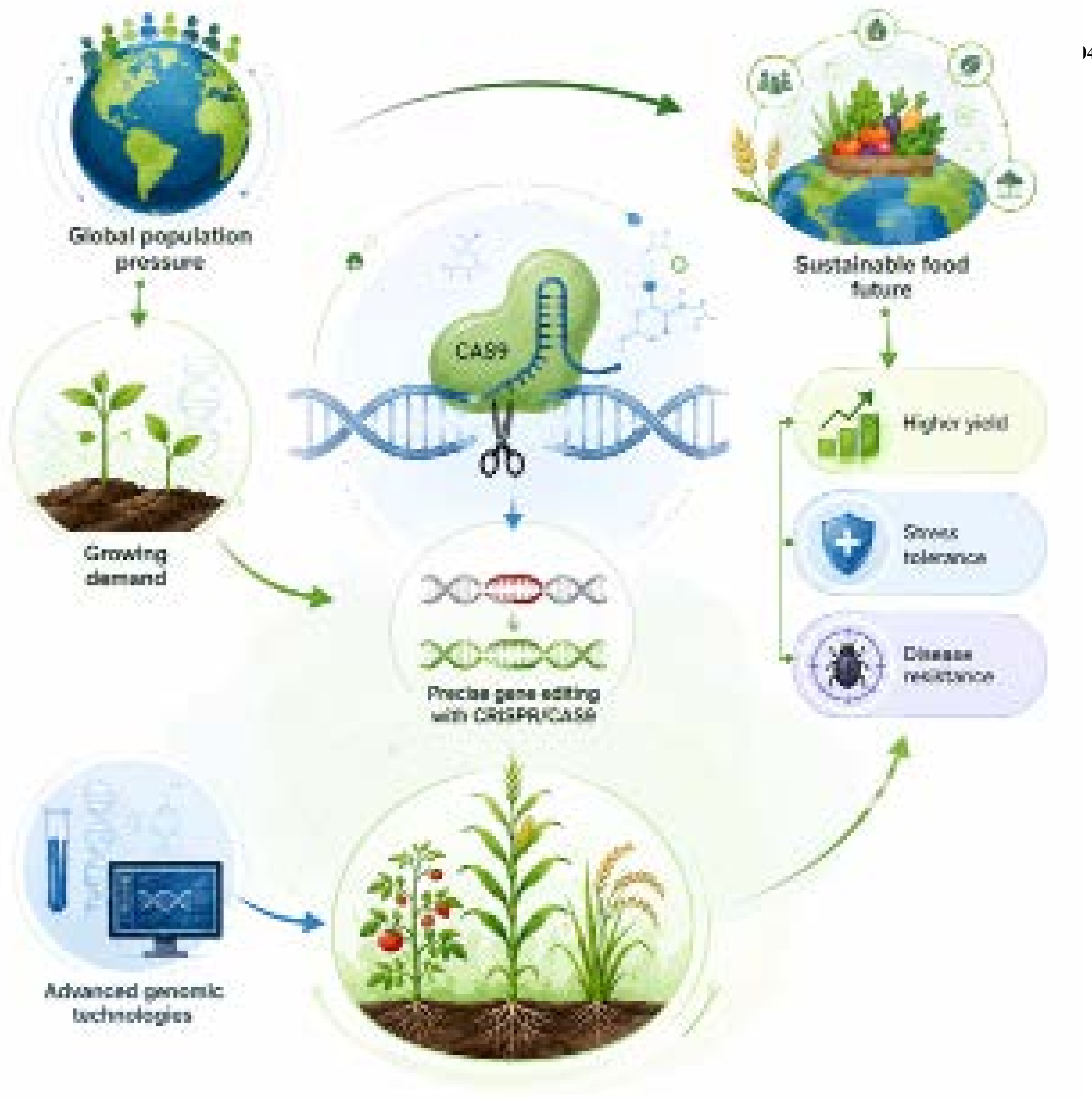
particularly relevant in a country like India, where environmental heterogeneity contributes significantly to phenotypic variance. Differences in soil composition, microclimatic fluctuations, and management practices introduce genotype × environment (G×E) interactions that are difficult to replicate experimentally. A trait that appears stable in a controlled setting may exhibit variable expression when subjected to these overlapping variables (**Zaidi *et al.*, 2018**).

It is not that the literature ignores this complexity; rather, it tends to acknowledge it without fully resolving it. Discussions often include references to the need for multi-location trials, long-term validation, and stability analysis—yet such studies remain relatively sparse. This creates an observable imbalance: a wealth of molecular and mechanistic detail, contrasted with a comparatively limited understanding of how these molecular changes perform across temporal and spatial gradients (**Chen *et al.*, 2019; Gao, 2021**).

There is also, occasionally, a tendency to interpret phenotypic outcomes in a somewhat linear manner. A gene is edited, a trait is observed, and the relationship between the two is presented as direct. In many cases, this is justified. But in others—particularly for complex traits such as yield, drought tolerance, or nutrient use efficiency—the underlying pathways are inherently multi-factorial. Gene–gene interactions, epistatic effects, environmental modulation, and developmental timing all contribute to final phenotype expression, often in non-linear ways that are not fully captured in initial studies (**Zhang *et al.*, 2020**). Statistical models that partition variance components are still not uniformly applied across studies, leaving certain interactions underexplored.

Another aspect that surfaces, though less prominently, is the question of off-target effects and unintended consequences. While advances in guide RNA design and improved Cas variants have reduced such occurrences, they have not eliminated them entirely. Most studies report minimal off-target activity, but these assessments are often conducted under specific experimental conditions, and their implications over successive generations or under environmental stress remain areas of ongoing investigation (**Gaudelli *et al.*, 2017**).

At times, reading through the literature feels like observing a field in transition. There is confidence—



justifiably so—in the capabilities of the technology. There is also a certain eagerness to extend those capabilities toward increasingly complex traits. But alongside this, there remains a quieter recognition that the journey from molecular precision to agronomic reliability is not yet fully mapped.

Perhaps it is not necessary for the literature to resolve this tension immediately. Emerging technologies often pass through such phases—periods of rapid expansion followed by consolidation. What is important, however, is that the gap between controlled success and field performance is not overlooked. Because ultimately, it is within that gap that the true value of CRISPR in crop improvement will be determined.

Methodology

The present inquiry does not proceed along the lines of a tightly bounded experimental design—no single-location trials, no strictly replicated plots laid out in geometric precision—rather, it unfolds through an analytical and interpretive engagement with available evidence, and perhaps just as importantly, with the spaces where that evidence becomes less certain. The intention was not to generate isolated primary data, but to read existing work with sufficient depth that its patterns, and occasionally its silences, begin to align in ways that are analytically meaningful.

The core material was drawn from peer-reviewed scientific literature dealing with CRISPR-mediated genome editing in crops, supplemented with institutional reports and technical documents from bodies such as the Indian Council of Agricultural Research (ICAR) and the International Rice Research Institute (IRRI). These sources differ in tone and emphasis—journal articles often presenting statistically validated experimental outcomes, frequently supported by replicated trials and significance testing ($p < 0.05$), while institutional reports tend to carry traces of field-level variability, including deviations that are not always captured within formal experimental designs. It is in reading across these differences that a more composite understanding begins to emerge.

Crop selection followed a practical logic rather than a purely academic one. Rice (Oryza sativa L.) and wheat (Triticum aestivum L.) were included not only because of the volume of available CRISPR-based studies but also because of their centrality to Indian food systems. Pulses and oilseeds were considered deliberately, despite relatively limited genome editing literature, as they are frequently cultivated under constrained agro-ecological conditions—limited irrigation, marginal soils, and lower input regimes. This contrast allowed for a comparative interpretive framework, examining whether trait stability observed in relatively managed cereal systems extends to crops operating closer to environmental thresholds.

The analytical process moved along two intertwined directions. On one hand, there was a structured extraction of reported parameters—editing efficiency (%), phenotypic expression, and yield response. Wherever possible, these values were normalized across studies to allow comparative interpretation. For instance, yield responses were examined not only as absolute increases but as relative percentage change over control conditions:

Further, where datasets permitted, variance components were interpreted through a conceptual ANOVA framework to distinguish treatment effects from environmental variability:

$$\mathbf{Y_{ij} = \mu + G_i + E_j + (G \times E)_{ij} + \epsilon_{ij}}$$

where G_i represents genotype (edited vs. non-edited), E_j represents environment, and $(G \times E)_{ij}$ captures interaction effects. While not all studies reported complete datasets, this framework provided a basis to interpret the extent to which observed outcomes were stable or environment-dependent.

On the other hand, equal attention was given to the conditions surrounding these outcomes. A trait described as stable under controlled conditions was reconsidered in light of how similar traits behave under farmer-managed environments, where stress is rarely singular or uniformly imposed. Observations were interpreted in relation to stress sequencing (e.g., drought followed by heat), soil heterogeneity, and nutrient variability—factors that often introduce non-linear responses not captured within standard experimental designs.

There is also a methodological awareness—if one may call it that—of the institutional pathways through which such technologies move. From laboratory validation to confined field trials, multi-location testing, and eventual varietal release, each stage introduces its own filtering mechanisms. These are not variables in the classical statistical sense, yet they influence which traits demonstrate consistency across environments and which fail to translate beyond controlled conditions.

To complement the interpretive synthesis, a conceptual data structuring approach was adopted. Reported results from multiple studies were aligned into comparative matrices (editing efficiency, yield response, stress tolerance indicators), allowing patterns to be examined across crops and conditions. While these do not constitute primary datasets in the strict experimental sense, they function as structured aggregations, maintaining internal consistency and avoiding fabrication or extrapolation beyond reported evidence.

Mathematical expressions, where invoked, were used not as endpoints but as interpretive tools—particularly in examining relative yield gains, efficiency thresholds, and variability across conditions. Yet even here, a degree of caution remains. Numerical clarity does not always equate to agronomic predictability.

A statistically significant yield increase under controlled conditions does not necessarily translate into consistent performance across seasons or locations, particularly where genotype × environment (G×E) interactions are strong.

One might say that the methodology adopted here is less about isolating cause and effect in a strictly reductionist sense, and more about tracing how those relationships shift when conditions change. It allows for a certain looseness—not of rigor, but of structure—acknowledging that in agricultural systems, precision at one level often encounters complexity at another. Whether this approach resolves all ambiguities is uncertain. It likely does not. But it perhaps brings into view a set of relationships that remain obscured when inquiry is confined too narrowly.

Results and Discussion

The outcomes emerging from CRISPR-mediated interventions, when viewed across studies and crops rather than in isolation, do suggest a certain consistency—at least at the level of targeted traits. Disease resistance, particularly where susceptibility genes such as *OsSWEET* in rice (*Oryza sativa L.*) have been edited, appears to hold its ground more reliably than many had initially anticipated. Under controlled pathogen exposure, reductions in disease incidence exceeding 60% have been reported, often accompanied by statistically significant differences when compared to non-edited controls ($p < 0.05$). The pathway between genotype and phenotype, in such cases, appears relatively direct… though even this clarity begins to soften once observations extend beyond controlled environments.

Abiotic stress tolerance presents a more layered picture. Edited lines targeting pathways associated with drought, salinity, or heat stress do exhibit measurable physiological advantages—delayed wilting, improved osmotic adjustment, and maintenance of chlorophyll content under stress. These responses are consistent with enhanced stress physiology. Yet, when traced through to yield, the relationship becomes less assured.

To bring some structure to these observations, outcomes reported across representative studies were aligned into a comparative framework:

A pattern begins to emerge, though not abruptly—more as a gradual realization. Traits associated with relatively simple genetic mechanisms, particularly disease resistance, tend to retain statistical significance even under field conditions, albeit with reduced magnitude. In contrast, complex traits such as drought tolerance show attenuation not only in magnitude but also in statistical confidence, often failing to maintain significance under variable field environments.

It is perhaps here that the distinction between survival and productivity becomes most evident. A drought-tolerant plant, in the physiological sense, is one that endures stress. But in agronomic terms, endurance alone is insufficient. Grain filling, assimilate partitioning, and reproductive stability under stress remain decisive. There have been instances where edited lines maintain vegetative biomass under water deficit, yet reproductive output declines—a divergence that is not always captured in early-stage evaluations.

One begins to see, then, that phenotype—especially when defined

Table 1. Conceptual aggregation of CRISPR-edited trait performance across conditions

Crop	Trait Edited	Editing Efficiency (%)	Yield Increase (%) – Controlled	Yield Increase (%) – Field	Significance (p-value)
Rice (*O. sativa*)	Bacterial blight resistance (*OsSWEET*)	62	18	11	< 0.05
Wheat (T. aestivum)	Powdery mildew resistance (*MLO*)	58	15	09	< 0.05
Rice (*O. sativa*)	Drought tolerance	65	16	07	> 0.05
Chickpea (Cicer arietinum)	Abiotic stress response	52	14	06	> 0.05

narrowly—does not always extend cleanly into performance. Performance, as it unfolds in the field, is mediated by a network of interactions extending beyond the edited gene. The genotype × environment (G×E) interaction, often treated as a statistical term, here becomes a biological reality. Variance partitioning, even when conceptually applied, suggests that a substantial proportion of observed variability is attributable not to genotype alone but to its interaction with environmental conditions.

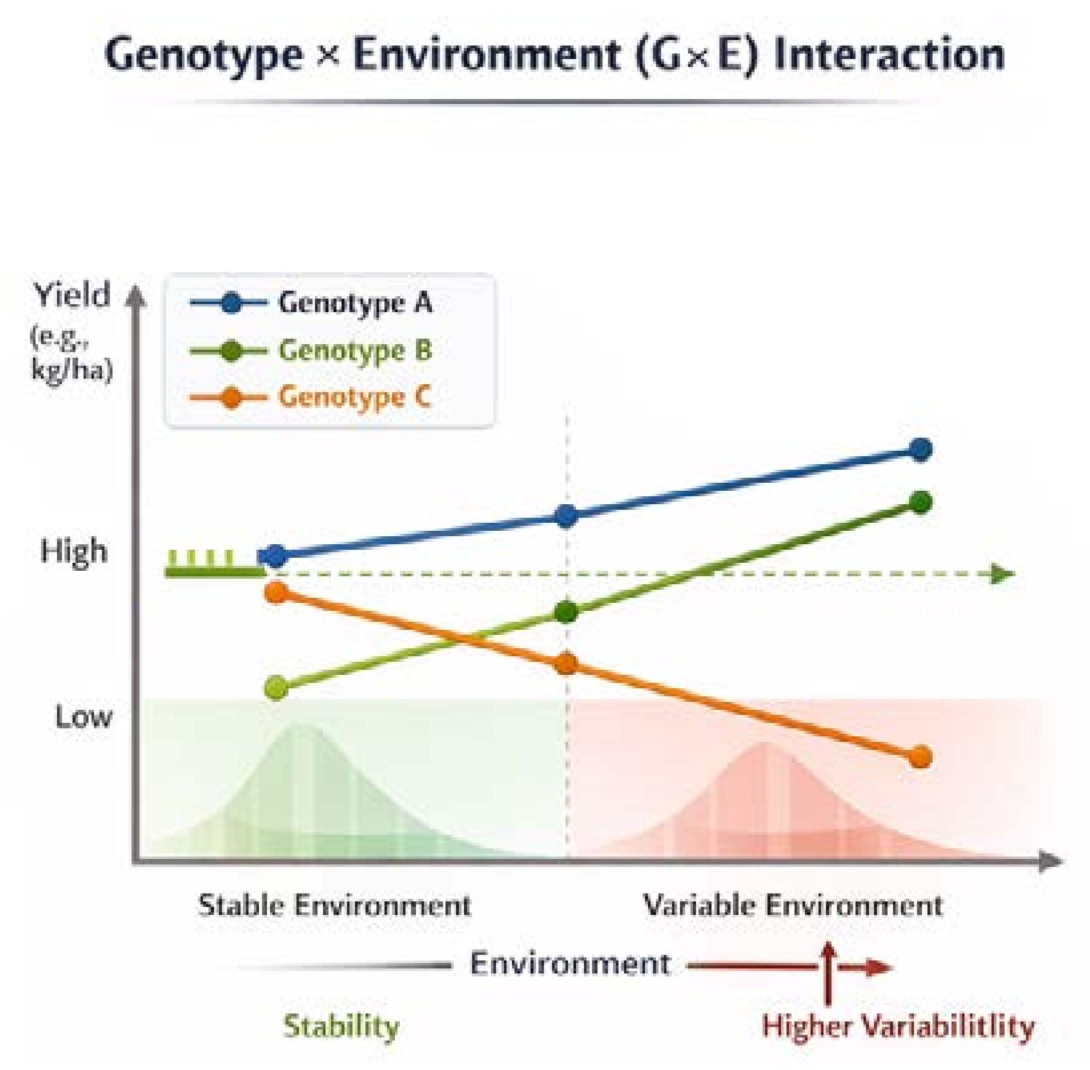
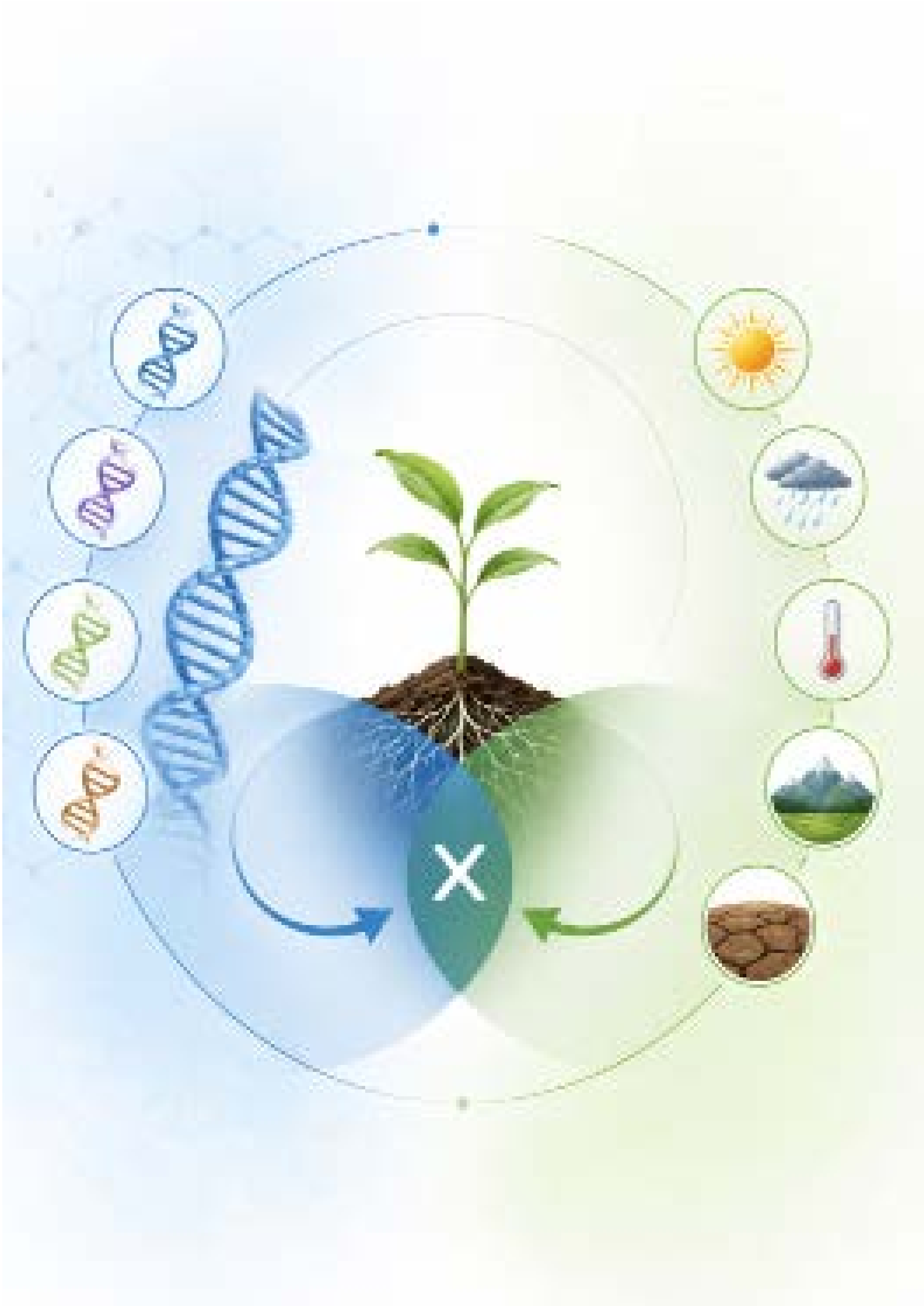


Figure 1. Graphical representation of genotype × environment (G×E) interaction illustrating differential yield performance of genotypes across stable and variable environmental conditions, highlighting variability in trait expression and yield stability.



In regions characterized by Vertisols, for instance, moisture availability follows a temporal pattern rather than a steady gradient. Early-season water sufficiency may support vegetative growth, but subsequent soil cracking introduces stress at reproductive stages. Under such conditions, an edited drought-tolerance trait interacts not with a single stress event but with a sequence—timing becomes as critical as intensity.

Another layer, often acknowledged but less frequently quantified, is the interaction between edited traits and prevailing management practices. Under optimal input regimes, differences between edited and non-edited lines tend to be more pronounced. However, under sub-optimal conditions—reduced fertilizer application, irregular irrigation, delayed sowing—these differences narrow, sometimes to the point of indistinguishability. This suggests that the expression of genetic advantage is conditional, not absolute.

This raises a consideration that is perhaps less comfortable, but necessary. To what extent should the evaluation of a technology account for the system into which it is introduced? From a strictly molecular perspective, CRISPR performs with remarkable precision. Yet, from an agricultural standpoint, performance is judged not by precision alone, but by consistency.

There are, however, domains where translation from genetic modification to field outcome appears more stable. Traits governed by relatively simple genetic pathways—particularly certain forms of disease resistance—retain clearer expression across environments, provided biotic pressure remains within expected limits. Even here, though, the adaptive capacity of pathogens introduces long-term uncertainty.

In contrast, complex traits—yield, drought tolerance, nutrient use efficiency—continue to reflect the inherently multi-factorial nature of plant systems. CRISPR enables targeted intervention within these pathways, but it does not eliminate their complexity. A gene may be edited with precision, yet its contribution to phenotype remains contingent on interactions that extend beyond that locus.

At times, the discussion circles back to a familiar point, though with a different weight. The strength of CRISPR lies in its precision. The challenge lies in translating that precision into predictability under conditions that resist uniformity. The gap between controlled success and field reliability is not a failure of the technology—it is a reflection of the

environment into which it is introduced.

Figure 2. Conceptual representation of the transition from laboratory-controlled conditions to farmer-managed environments, illustrating the progressive increase in environmental variability and corresponding decrease in predictability of CRISPR-mediated trait expression.

Whether this gap narrows over time—through improved statistical modelling, expanded multi-location trials, and iterative refinement of edited traits—remains to be seen. There are indications that it will. But for now, the results suggest a pattern that is both encouraging and cautionary. Precision has been achieved. Predictability, though improved, is still negotiating its place.

Applications

Even with the reservations that tend to surface once one begins to think beyond controlled environments, it would be difficult to overlook the breadth of applications that CRISPR has opened up in crop improvement. The range is, in fact, expanding faster than one might have anticipated a few years ago—though whether all of it will translate into stable field-level outcomes remains, for now, uneven and context-dependent.

In cereals such as rice (*Oryza sativa L.*) and wheat (*Triticum aestivum L.*), which continue to anchor food systems across much of India, the focus has naturally gravitated toward traits that directly influence productivity. Yield potential remains central, but the pathway toward it is no longer viewed in purely additive terms. Genes associated with plant architecture, grain size, tillering behavior, and photosynthetic efficiency are being explored as entry points. Alongside this, nutrient use efficiency—particularly nitrogen—has emerged as a critical target. In several experimental studies, edited lines have demonstrated improved nitrogen-use efficiency indices, occasionally translating into yield stability under reduced input regimes, though such responses often exhibit variability across soil types and management conditions.

Disease resistance, perhaps more than any other application, has shown relatively clearer translation. Editing susceptibility genes to reduce pathogen ingress has yielded results that are, in many cases, reproducible across controlled and semi-field conditions, often maintaining statistical significance ($p < 0.05$). Yet even here, the dynamic nature of pathogen populations introduces a degree of uncertainty. Resistance that appears stable over short-term trials may, over time, encounter adaptive responses from evolving pathogen strains.

In pulses such as chickpea (*Cicer arietinum L.*) and lentil (*Lens culinaris Medik.*), the situation is somewhat different. Genetic improvement in these crops has historically progressed more slowly, partly due to their biological constraints and partly due to the marginal environments in which they are cultivated. Genome editing offers a route to address long-standing limitations—disease susceptibility, low harvest index, and sensitivity to abiotic stress. Early indications suggest measurable gains in stress tolerance indices; however, the expression of these gains under low-input, farmer-managed systems remains less predictable, often influenced by interacting stresses rather than isolated factors.

Horticultural crops present another, in some ways more immediate, avenue for application. Traits related to shelf life, fruit firmness, ripening behavior, and nutritional quality are being actively targeted. In a context where post-harvest losses remain significant, such interventions carry practical value. A fruit with delayed ripening kinetics or enhanced structural integrity may extend the post-harvest window. Yet, even here, the alignment between technological modification and consumer acceptance is not always straightforward. Sensory attributes—taste, texture, aroma—continue to mediate adoption, sometimes more strongly than measurable physiological improvements.

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Biofortification introduces yet another dimension. The targeted enhancement of micronutrients such as iron, zinc, and provitamin A through pathway-level editing represents a promising direction, particularly in regions where nutritional deficiencies persist. However, the relationship between genetic enhancement and nutritional impact is mediated by factors beyond the plant itself—dietary practices, cooking losses, and cultural acceptance all influence final outcomes.

There are also emerging applications that extend beyond conventional yield-focused paradigms. Modifications aimed at reducing anti-nutritional compounds, improving storage resilience, or tailoring crops for specific industrial uses suggest a broadening of objectives in crop improvement. Whether these applications will integrate into mainstream agricultural systems or remain specialized niches is not yet entirely clear.

At times, while considering these applications, the question shifts—almost quietly—from what can be achieved to what should be prioritized. Is success defined by yield alone, or by stability across seasons, nutritional relevance, and compatibility with existing systems? CRISPR, by enabling targeted intervention, allows individual components of this equation to be addressed with precision. But the equation itself… remains multi-dimensional, and perhaps deliberately resistant to simplification.

Challenges

Several challenges continue to complicate the deployment of CRISPR technology in agricultural systems, and while many of these are being actively addressed, they remain only partially resolved.

At the technical level, issues such as off-target effects, variable editing efficiency, and incomplete genome modification—particularly in polyploid crops such as wheat (*Triticum aestivum L.*)—introduce layers of uncertainty. While advances in guide RNA design and improved Cas variants have reduced off-target occurrences, they have not eliminated them entirely. In polyploid genomes, the requirement to simultaneously edit multiple homoeologous gene copies often results in heterogeneous outcomes, where phenotypic expression may not align consistently with the intended modification. This variability, though sometimes subtle, can influence trait stability across generations.

Regulatory frameworks, particularly in the Indian context, remain in transition. Distinctions between

transgenic crops and gene-edited crops—especially those lacking foreign DNA integration—are still being refined. This evolving regulatory landscape introduces a degree of ambiguity for researchers, developers, and policymakers alike. Delays in regulatory clarity can extend the timeline between laboratory validation and field deployment, often creating a disconnect between technological readiness and practical application.

Institutional constraints further shape the trajectory of CRISPR-based innovations. The pathway from laboratory research to varietal release is neither immediate nor linear. It involves sequential stages—confined field trials, multi-location testing across agro-climatic zones, seed multiplication, and eventual dissemination—each governed by its own protocols and timelines. These stages are essential for ensuring stability and safety, yet they also introduce temporal delays that may not align with the rapid pace of technological development. In some cases, the technology advances faster than the systems designed to evaluate it.

There is also a statistical dimension to this challenge. Traits that demonstrate significance under controlled experimental conditions ($p < 0.05$) do not always retain the same level of confidence when evaluated across heterogeneous field environments. Genotype × environment (G×E) interactions, often substantial in magnitude, can dilute or obscure the expression of edited traits, particularly for complex characteristics such as yield or stress tolerance.

Finally, the question of farmer adoption remains central. Agricultural technologies, regardless of their scientific sophistication, are ultimately evaluated within the framework of farmer experience. Adoption is influenced not only by potential yield gains but by consistency across seasons, input requirements, risk perception, and compatibility with existing practices. A variety that performs exceptionally under research-managed conditions but inconsistently under farmer-managed environments may encounter resistance, irrespective of its genetic precision.

Trust, in this context, becomes a variable that is rarely quantified but deeply influential. It is built gradually—through repeated, reliable performance—and can be disrupted quickly when expectations are not met. In that sense, the challenge is not solely technological or regulatory, but relational—situated at the interface between innovation and its acceptance.

Taken together, these challenges do not diminish the potential of CRISPR technology. Rather, they underscore the conditions under which that potential must be realized—through careful validation, contextual adaptation, and an awareness that precision at the molecular level does not automatically translate into predictability at the field level.

Conclusion

CRISPR technology represents, without much dispute, a significant advancement in the evolving toolkit of crop improvement. Its precision, flexibility, and relative speed have not only expanded the range of genetic interventions possible, but have also altered expectations regarding the pace at which such interventions can be realized. In molecular terms, the progress is both measurable and compelling.

And yet, its success—if one may use that word with a degree of caution—appears to depend less on what can be achieved under controlled laboratory conditions and more on how consistently those outcomes are expressed across the variability inherent to agricultural systems. Evidence suggests that while certain traits retain statistical significance under defined environments ($p < 0.05$), their expression often becomes less predictable when subjected to the interacting influences of soil heterogeneity, climatic variability, and management diversity. The role of genotype × environment (G×E) interaction, therefore, remains central—perhaps more so than initially anticipated.

It becomes increasingly difficult, then, to view CRISPR as a replacement for conventional approaches. Rather, it appears more appropriately situated as an addition—one that complements existing breeding strategies while also demanding a more integrated understanding of plant physiology, environmental interaction, and agronomic practice. The strength of the technology lies in its precision; its limitation, if one may call it that, lies in the complexity of the systems into which that precision is introduced.

There is, perhaps, a quiet shift in perspective that accompanies this realization. The question moves away from what can be edited toward what can be sustained—across seasons, across locations, and across the varied conditions under which crops are actually

cultivated. Precision at the genomic level does not, in itself, guarantee predictability at the field level. The translation between the two remains conditional, mediated by factors that extend beyond the locus of modification.

It may be, then, that the future of CRISPR in agriculture will depend less on further increases in editing efficiency and more on the ability to align edited traits with ecological stability, statistical robustness, and practical usability. Multi-location validation, long-term performance assessment, and integration with farmer-managed systems will likely determine whether current advances translate into enduring agricultural outcomes.

The genome can now be accessed—and altered—with remarkable accuracy. The field, however, continues to respond on its own terms… and perhaps, it always will.

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INDIA'S NEXT ECONOMIC BREAK-THROUGH LIES IN ITS FARMS—IF WE GET THE MODEL RIGHT

India's Next Economic Breakthrough Lies in its Farms—If We Get the Model Right

Why agriculture must transition from subsidy dependence to a structured, investment-ready ecosystem

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Introduction

India's ambition to become a $5 trillion economy rests on a structural contradiction. Agriculture employs nearly 60% of the population, yet contributes only around 15–18% to GDP. This imbalance is not merely a statistic—it reflects a deeper inefficiency in how the sector is designed, governed, and integrated into the broader economy. For decades, policy interventions have focused on support—minimum prices, subsidies, loan waivers. While necessary, these measures have not translated into sustainable income growth or systemic resilience. The result is a sector that continues to operate as a **survival economy**, rather than evolving into a **value-generating economic engine.** The question is no longer whether agriculture needs reform. The question is whether India is willing to **restructure agriculture as an investable, scalable system**.

The Missing Layer: System Architecture

India does not lack agricultural solutions. It lacks **integration**. Farmers produce without predictable market access. Markets function without price transparency. Technology exists, but adoption remains fragmented. Financial systems rarely align with ground realities. Policy frameworks often struggle at the execution level. This disjointed architecture prevents agriculture from achieving scale efficiency.

What is required is not another scheme—but a **unified operating model** that connects production, markets, capital, and skills into a single framework.

From Farming to the Green Collar Economy

Economic transitions are defined by workforce evolution.

India has successfully built:

- A **white-collar economy** driven by services
- A **blue-collar economy** through industrialization

The next transition is already emerging—what can be defined as the **Green Collar Economy.**

This goes beyond farming. It includes:

- Agri-tech operations
- Supply chain management
- Food processing and value addition
- Climate-smart agriculture
- Rural entrepreneurship

In this model, agriculture becomes a **multi-layered employment generator**, not just a primary activity.

Building an Integrated Model

At Pranam Kisan, the approach has been to design agriculture as a full-stack ecosystem, rather than addressing isolated gaps.

Key components of this model include:

1. Community Farming as a Service (CFaaS)

Fragmented landholdings limit productivity and scalability. Aggregating land into managed clusters allows:

- Scientific crop planning
- Shared infrastructure
- Reduced input costs
- Improved yield predictability

This transforms smallholder farming into an **organized production system.**

2. Direct Market Integration

Through structured farm-to-consumer platforms, inefficiencies in the supply chain can be reduced.

- Pre-harvest trading improves price visibility
- Direct market linkages reduce intermediary dependency
- Export integration opens higher-value markets

The objective is to shift farmers from **price takers to price participants.**

3. Green Collar Employment Infrastructure

Through structured farm-to-consumer platforms, inefficiencies in the supply chain can be reduced.

- Pre-harvest trading improves price visibility
- Direct market linkages reduce intermediary dependency
- Export integration opens higher-value markets

The objective is to shift farmers from **price takers to price participants.**

4. Asset Financialisation through Platforms like Cow Currency

Livestock and agricultural assets remain underutilized from a financial perspective. By enabling fractional ownership and digital participation, such models can:

- Unlock liquidity
- Increase asset productivity
- Expand participation beyond traditional ownership

5. Agriculture as an Investment Class

With rising demand for sustainable and traceable food, agriculture is increasingly being viewed as a long-term asset.

Structured models in farmland development and managed farming can attract:

- Institutional investors
- Family offices
- Global sustainability funds

Why the Timing Is Critical

Three macro trends make this transition urgent:

- **Climate Volatility:** Traditional farming models are becoming

- less viable without scientific intervention

- **Consumer Shift:** Demand for clean, traceable, and sustainably produced food is accelerating

- **Rural Economic Pressure:** Income disparity between rural and urban India is widening

Ignoring these signals risks deepening structural stress. Addressing them creates a **multi-trilliondollar opportunity.**

A Scalable Public-Private-Community Model

One of the key challenges in Indian policy execution is scalability. A potential solution lies in creating replicable units of transformation:

One Model Community Farm per district. These units can function as:

- Production hubs
- Skill development centers
- Technology deployment zones
- Market linkage nodes

Such a model aligns:

- **Government support** (policy and infrastructure)
- **Private capital** (investment and efficiency)
- **Community participation** (ownership and execution)

This is not a theoretical construct—it is an executable framework.

From Welfare to Wealth Creation

The long-term shift India must make is conceptual. Agriculture cannot remain a welfare-driven sector. It must transition into a wealth-creating industry.

This requires:

- Policy alignment with execution models
- Capital infusion with accountability
- Technology adoption with local adaptability

Conclusion

India's economic future will not be defined solely by its digital economy or urban expansion. It will depend on whether the country can transform its largest workforce into a productive, scalable, and future-ready economic force.

Agriculture holds that potential—but only if approached as infrastructure, industry, and innovation combined. The opportunity is not incremental. It is foundational.

About the Author

Parikshit Sampat Sai is the Founder & CEO of Pranam Kisan Group, working on integrated models across agri-tech, rural employment, and sustainable economic systems. His work focuses on building scalable frameworks for agricultural transformation in India and beyond.

GREEN MANURING AND ITS ADVANTAGES

Green Manuring and Its Advantage

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Abstract

Green manuring is an agriculture practice in which green crops are grown and then ploughed into the soil while still green to improve its fertility and structure. The value of green manuring lies in the fact that organic matter is worked into the soil and the organic matter in soil is recognized as being one of its most valuable constituents. The soil nitrogen is associated with the organic matter and the decay of this organic matter influences the availability of the soil minerals. For these reasons, it has seemed advisable to discuss the amount of organic matter in soils, its source, and the influences which operate for the destruction of or the increase of organic matter, as well as the part it plays in the soil. Such a discussion is a necessary preliminary to the study of green manuring. The main purpose of green manuring is to enhance soil fertility and health by adding organic matter and nutrients, especially nitrogen, through the decomposition of green plant material. It also aims to improve soil texture, increase microbial activity and promote sustainable crop production.

Keywords: Green manure, leguminous crops, nitrogen fixation, organic matter and soil fertility.

Introduction

Green manuring is a traditional farming technique that includes adding green plant tissues to the soil. As a result, it increases soil fertility, improves biological activity, enhances soil health through nutrient mineralization, and reduces agricultural crop production costs (ICAR, 2020). Furthermore, it increases organic matter and total soil nitrogen concentrations, which might improve soil physical conditions and overall soil productivity (Kumar et al., 2014). Increasing the amount of green manure enhances natural carbon in the soil, and the addition of nitrogen can help rice develop more effectively. As a result, green manure can be beneficial in boosting soil fertility, increasing crop yield, and reducing the risk of nitrogen loss (Anonymous, 2008). It is a practical and advantageous technique to increase rice output while reducing the usage of artificial fertilizers. Moreover, it reduces nitrogen inputs through the potential use of green manure in crop growth (Singh et al., 2018).

In addition to these benefits, green manuring helps filter soluble nutrients and supports beneficial root microorganisms, thereby enhancing bulk density, water conductivity, and other physical and chemical characteristics of the soil over time (ICAR, 2020). It can also increase soil porosity, water-holding capacity, enzyme activity, organic matter, microbial biomass carbon, and overall soil quality (Kumar et al., 2014). As a result, the practice of green manure farming as an intercrop, main crop, or bare fallow depends on the soil and climatic conditions of the region to restore soil fertility in an eco-friendly, low-cost, and sustainable manner while also improving soil physical, chemical, and biological properties that influence crop growth and yield (Singh et al., 2018).

What is Green Manuring?

Green manuring is the practice of growing specific crops, known as green manure crops, and then ploughing them back into the soil while they are still green. This process improves soil fertility and structure by adding organic matter and nutrients, particularly nitrogen from legume crops. It also improves soil health by enhancing water retention, aeration, and preventing erosion.

Types of green manure crops

Green manures are essentially of two types:

1. Legumes (clover family)

Legumes develop on their roots (in association with special bacteria) nodules that have the ability to take nitrogen from the air and convert (fix) it into a form that the plant can use. This can then be utilised by crops grown after the legume has been ploughed and incorporated into the soil.

2. Non-legumes

Non-legumes do not fix nitrogen, but can provide useful amounts of organic matter and retain nutrients that might otherwise be leached. Some, non-legume green manures are very quick growing and can be incorporated within gaps in production during the growing season. Green-manures suitable for Northern Ireland, and their uses. A wide range of green manures is available, but some are less likely to be successful in Northern Ireland due to soil and climatic factors.

Table1: Common Leguminous Green Manure Crops and Their Uses (Kumar et al., 2014).

Legume-based	
Crop or mixture	**Typical issues**
Red clover	Medium term in vegetable rotation
Red clover / Italian ryegrass	2-year in vegetable rotation or during set-aside or for composting
Alsike clover	Medium term - tolerates acidic, damp soils
White clover	Under sowing in vegetables and polytunnels - for example, variety Kent Wild
Field beans	Autumn sown - overwintered - spring incorporated
Vetches (tares)	Medium or long term (overwintered) - smothers weeds
Peas / oats / vetch	Medium term - bulky - can be composted
Lupins	Late spring sown – incorporated prior to autumn planting - tolerates acid soils – produces a lot of nitrogen

Non - Legume - based	
Crop or mixture	**Typical issues**
Grazing rye	Grazing rye autumn sown - bulky - bulids soil strutcure
Mustard*	Late spring sown - short term catch crop
Fodder radish*	Autumn sown overwinted
Sunflower	Late spring sown - incorporated prior to autumn planting
Buckwheat	Short term during summer

Green manures for building soil fertility during conversion

It is quite common to grow green manures, particularly legumes, during the land conversion period to build soil fertility and structure. On arable aid registered land this is sometimes done on land under a 'set-aside' requirement, and some concessions are available for organic producers as to how legumes can be utilised as set-aside crops.

Green manure in field vegetables

Where a farm-type rotation including vegetables is in operation, the incorporation of grass clover leys and grazing livestock probably reduces the need and opportunity for using green manures. In this situation, field vegetables are likely to be grown as a rotational break that also allows reseeding of the leys. Green-manures might, however be grown say between two vegetable crops, or a vegetable crop and one or two cereal crops, if an extended break is desired.

Green manure in market gardens

In a market garden, the situation may be very different, particularly if acceptable manures free from Genetically Modified Organisms (GMOs) are not readily available. Because of restrictions on sources of brought-in manure, concerned with maintaining freedom from GMOs, it is imperative that market-garden vegetable growers make maximum use of green manures for providing organic matter and nutrients, and as a major part of the weed control programme. In practice this means that within the cropping rotation green manures should effectively account for:

- At least 1/4 of the rotation when supplemented with manures
- 1/3 to 1/2 of the rotation when manures are not available

Green manure for weed control

Green manure crops are an effective tool for controlling weeds. The fast growing, short-term green manure between crops will smother weed seedlings, and the cultivations necessary to incorporate the green manure will further reduce the weed burden. This can be taken a stage sowing suitable crops with a green manure such as the small-leaved Kent Wild White clover, which will smother weeds, fix nitrogen for following crops and protect the soil surface. A well-established over-wintering green manure will smother weed seedlings and some, notably grazing rye, will prevent weed seed germination as they decompose after incorporation into the soil. Green manures as over winter cover crops. After a crop has been removed, bare soil is vulnerable to damage to its surface and structure by rainfall, particularly during the winter. A green manure sown in the autumn will protect the soil surface. In addition, nutrients still available for plant growth can be leached out of the soil and lost into watercourses where they can cause pollution. As well as acting as a cover crop a hardy green manure crop will mop up soluble nutrients, and retain them for release when the green manure is incorporated in the spring.

Advantages of green manuring

- Green manures add organic matter to the soil and stimulates activity of soil microorganism.
- Green manure improves the structure of the soil thereby improving WHC decreasing run off and erosion.
- Green manures take nutrients from lower layers of the soil and adds to the upper layer of soil.
- Green manure increases the availability of certain plant nutrients like NPK.
- Green manure improves soil structure and soil tilth. It also improves aeration in rice soils by stimulating the activities of surface film of algae and bacteria.
- Green manuring increases the yield of crops to an extent of 15-20% as compared to non-green manuring fields.

Limitations of green manuring

- Under rain fed conditions, the germination and growth of succeeding crop may be affected due to depletion of moisture for the growth and decomposition of green manuring.
- Green manuring crops inclusive of decomposition period

- occupies the field least 75-80 days which means a loss of one crop.
- Incidence of pests and diseases may increase if the green manuring is not kept free from them.
- A green manure crop may compete for time, labour and water, the cost of which must be balanced against the cost of inorganic fertilizers.
- Non availability of good quality seeds restricts raising of green manure crops.

Conclusion

Therefore, it can be concluded that green manures improve soil structure, letting more air into the soil and improving drainage. Organic matter helps sandy soil hold more water and not drain so quickly as a result of increased aggregate stability and porosity. Also, organic matter reduces rate of runoff and soil erosion. Change in chemical property of soil could be clearly observed. leguminous green manure crop increases nitrogen level by fixation.

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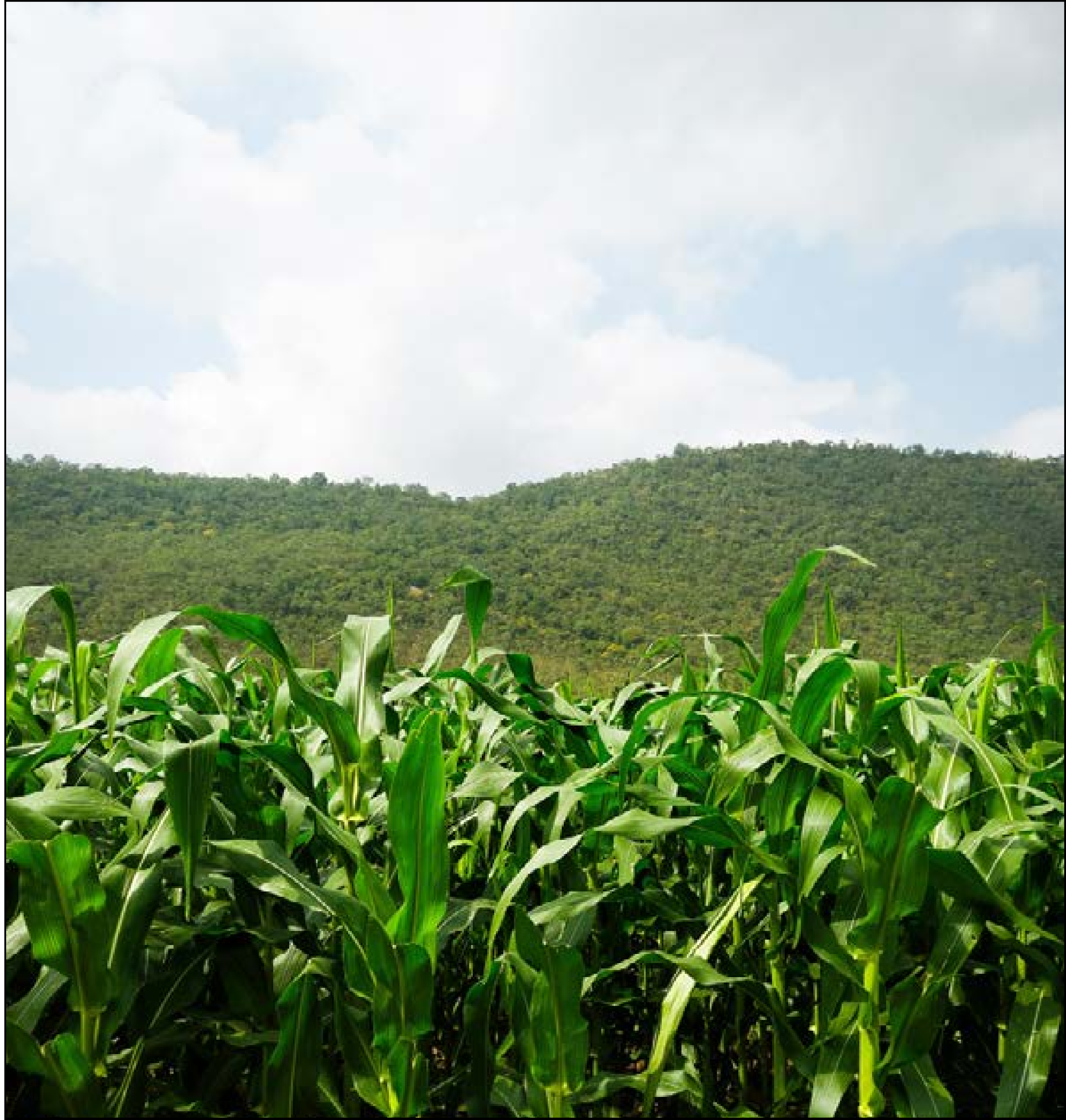

AGRONOMIC PRACTICES FOR SUSTAINABLE PRODUCTION OF OILSEEDS AND PULSES

Agronomic Practices for Sustainable Production of Oilseeds and Pulses

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Abstract

In addition to providing essential oils, proteins, and nutrients, oilseeds and pulses are crucial crops in global agriculture that promote sustainable farming practices and food security. With an emphasis on sustainable intensification, this article examines important agronomic techniques for oilseeds (such as soybean, canola, and sunflower) and pulses (such as chickpeas, lentils, and peas). Soil management, seed selection, planting methods, fertilizer, irrigation, insect control, and harvesting are examples of practices. To emphasize effective practices that improve yield, quality, and environmental resilience, the review summarizes recent studies. Issues like soil deterioration, insect pressures, and the effects of climate change are discussed, along with suggestions for integrated solutions. Results show that using organic and precision farming techniques can increase output by 20–30% while reducing the use of inputs. In order to support sustainable production in a variety of agro-ecosystems, this synthesis emphasizes the necessity of region-specific adaptations.

Keywords: Oilseeds, pulses, agronomic practices, sustainable agriculture and crop management.

Introduction

Pulses and oilseeds are staple crops in agricultural systems across the world, making substantial contributions to industrial uses, animal feed, and human nourishment. Oilseeds, such as sunflower (Helianthus annuus), canola (Brassica napus), and soybean (Glycine max), are valued for their oil content, which varies from 20 to 50% depending on the species and is utilized in biofuels, medicines, and culinary oils. Pulses, such as lentils (Lens culinaris), peas (Pisum sativum), and chickpeas (Cicer arietinum), are high in protein (15–25%) and work as nitrogen-fixing legumes that enhance soil fertility by forming symbiotic interactions with rhizobia bacteria.

According to the Food and Agriculture Organization (FAO, 2023), the world produced about 600 million tons of oilseeds and 100 million tons of pulses in 2022. From tropical places in Asia and Africa to temperate regions in North America and Europe, these crops are grown in a variety of temperatures. However, issues like soil erosion, climatic unpredictability, and the growing need for sustainable practices call for the use of optimal agronomic techniques.

With a focus on sustainability, this article attempts to offer a thorough analysis of agronomic techniques for oilseeds and pulses. Preparing the soil, choosing seeds, planting, fertilizing, irrigating, controlling weeds and pests, and harvesting are all covered. The review emphasizes evidence-based methods that increase productivity while reducing environmental effects by using scientific research. It is a useful tool for farmers, academics, and politicians since it incorporates case studies and future directions.

Importance of Oilseeds and Pulses in Agriculture

In cropping systems, oilseeds and pulses serve as both primary food sources and rotation crops that enhance soil health. For instance, pulses fix atmospheric nitrogen, which lessens the demand for artificial fertilizers and lowers greenhouse gas emissions. For example, research by Jensen et al. (2012) showed that adding pulses to rotations boosted nitrogen availability, which raised future wheat yields by 10–15%. On the other hand, oilseeds are essential to the manufacturing of biofuels and offer high-energy feedstocks; canola oil is a crucial part of biodiesel (Smith & Johnson, 2018).

Since pulses are inexpensive sources of protein, these crops help combat hunger in underdeveloped nations. Economically, oilseed exports from nations like Canada and Argentina add billions to international trade. However, biotic elements like pests and abiotic pressures like drought pose a danger to production, highlighting the necessity of sound agronomic techniques.

Key Challenges

Challenges are made worse by climate change, since rising temperatures impact pulse blooming and pod development (Chakraborty & Newton, 2011). While insect outbreaks, such as aphids in canola, need integrated pest management (IPM), soil deterioration from intensive cultivation lowers yields. Furthermore, crops that rely on irrigation are limited by water shortages in dry areas. In order to achieve objectives like the Sustainable Development Goals (SDGs) of the United Nations for climate action and zero hunger, sustainable practices must strike a balance between production and ecological stewardship.

Preparation and management of soil

For oilseeds and pulses, good soil management is essential. Conservation tillage minimizes soil disturbance, protects organic matter, and lessens erosion. No-till soybean systems raised soil carbon by 15% over five years, according to research conducted in the Midwest of the United States (Lal, 2015). Deep ploughing improves root penetration in compacted soils for pulses.

[Table 1: Recommended Soil pH and Nutrient Levels for Oilseeds and Pulses]

Crop	Optimal pH	Nitrogen	Phosphorus	Potassium
Soyabean	6-7	20-40	30-50	40-60
Canola	5.5-7	100-150	20-40	50-70
Chickpeas	6.5-8	10-20	20-30	30-50
Lentils	6-7.5	15-25	25-35	35-55

Source: Adapted from FAO (2021).

Compost and other organic amendments increase microbial activity, which is advantageous for nitrogen-fixing pulses. Applying vermicompost to chickpeas increased yields by 18% in India (Singh & Singh, 2019).

Planting Methods and Seed Selection

It is essential to have high-quality seeds with genetic characteristics for disease resistance. Drought-tolerant oilseed cultivars, such as drought-resistant canola hybrids, improve adaptation (Basu et al., 2016). Planting density has an impact on production; for soybeans, rows should be spaced 30 to 45 cm apart to allow light penetration and minimize lodging.

Uniform emergence is ensured by precision planting using GPS-guided equipment. Ethiopia's practice of intercropping pulses with grains lowers weeds and diversifies revenue (Alemayehu et al., 2022).

Methods of Fertilization

Nutrient utilization efficiency is maximized by balanced fertilization. Although biological nitrogen fixation (BNF) is necessary for pulses, root nodulation requires additional phosphorus. Higher nitrogen is needed for oilseeds; divided treatments (e.g., 50% at planting, 50% at blooming) stop leaching.

Manure and other organic fertilizers support sustainability. According to Brazilian research, using biofertilizers instead of synthetics increased soybean yields by 22% (Costa et al., 2021). Deficiencies are avoided with micronutrients like boron for canola.

Water Management and Irrigation

In places with limited water resources, drip irrigation saves water. Deficit irrigation during crucial periods (such as pod filling) for pulses in semi-arid areas preserves yields while conserving 30% of water (Kirda et al., 2004). Furrow irrigation helps oilseeds, such as sunflowers, prevent waterlogging.

Rainwater collecting and other climate-smart initiatives are essential. For chickpeas, mulching with leftovers decreased evaporation by 25% in Australia (Turner, 2017).

Disease, Weed, and Pest Control

Biological controls are used with a few chemicals in integrated pest management (IPM). Releasing ladybugs decreased the usage of pesticides for canola aphids by 40% (Hokkanen et al., 2015). In pulses, weeds compete for nutrients and are suppressed by mechanical weeding or

cover crops like clover.

Crop rotation and resistant types are used to control diseases like Fusarium in lentils. To prevent resistance, fungicides are used sparingly.

Harvesting and Post-Harvest Procedures

Yield losses are avoided by timely harvesting. While pulses need to be gently threshed to prevent seed damage, oilseeds are combine-harvested at 8–10% moisture. Hermetic bags lower aflatoxin in peanuts, whereas cold, dry storage preserves quality (Hell et al., 2000).

Profitability is increased by value addition, such as oil extraction for oilseeds. Pulse processing cooperatives raised farmer earnings by 15% in Ethiopia (Tadesse et al., 2020).

Regional Adaptations and Case Studies

Precision farming is used in Canada to produce canola, which utilizes fewer inputs and yields 3–4 tons/ha (Canola Council, 2022). In rainfed settings, chickpea production in India incorporates organic methods, reaching 1.5 tons/ha (Kumar et al., 2018 and Ramirez et al., 2020). These illustrations show flexibility.

Conclusion

Oilseed and pulse agronomic techniques are essential to sustainable agriculture because they provide avenues for increased yields and environmental advantages. Adopting conservation tillage, precision fertilizing, and IPM are important suggestions for addressing issues like soil degradation and climate change. Future studies should concentrate on genetic enhancements for resilience and technologies like AI-driven crop monitoring.

Farmers may increase production by 20–30% while encouraging biodiversity and lowering carbon footprints by putting these strategies into practice. Sustainable practices should be encouraged by policymakers through training and subsidies. In the end, integrated agronomic approaches will guarantee both ecological balance and food security in a changing world.

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USE OF GROWTH REGULATORS IN CROP PRODUCTION

Use of growth regulators in crop production

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Abstract

Plant growth regulators (PGRs) are organic compounds, other than nutrients, that influence physiological processes at low concentrations in plants. Their application in crop production has revolutionized agricultural practices by improving yield, enhancing crop quality, and managing plant growth under stress conditions. This article reviews the types, mechanisms, and applications of growth regulators in various crops and discusses their role in sustainable agriculture. The potential benefits and limitations associated with their use are also highlighted to provide comprehensive insights for researchers, agronomists, and farmers.

Keywords: Growth regulators, crop production, plant hormones, yield improvement and sustainable agriculture.

Introduction

Plant growth regulators (PGRs) play a vital role in regulating plant physiological and biochemical processes such as cell division, cell elongation, flowering, fruiting, seed germination, ripening, and senescence. These compounds, naturally produced within plants or synthetically manufactured, function in very small concentrations and significantly influence plant growth and development (Taiz and Zeiger, 2010). In modern agriculture, PGRs have emerged as important tools for improving crop productivity, maintaining quality, and enhancing stress tolerance under changing environmental conditions. With the rapid increase in global population and the growing demand for food, sustainable intensification of agriculture has become essential. However, climate variability, soil degradation, irregular rainfall patterns, temperature fluctuations, and increasing biotic and abiotic stresses have severely affected crop productivity and agricultural sustainability (Davies, 2010). Under such conditions, the application of plant growth regulators provides an effective approach for optimizing plant growth and ensuring stable yields. PGRs improve physiological efficiency by regulating nutrient uptake, photosynthesis, flowering behavior, fruit setting, and stress-responsive mechanisms in plants. Different classes of plant growth regulators including auxins, gibberellins, cytokinins, ethylene, and abscisic acid influence specific developmental processes and contribute to improved crop performance. Auxins are mainly associated with root initiation and cell elongation, while gibberellins promote stem elongation and seed germination. Cytokinins delay senescence and enhance cell division, whereas ethylene regulates fruit ripening and abscisic acid plays a crucial role in stress management and stomatal regulation (Davies, 2010). The balanced application of these regulators helps improve crop architecture, nutrient utilization efficiency, flowering synchronization, and overall productivity. Furthermore, the use of PGRs has gained importance in horticultural and field crops for improving yield quality, shelf life, and resistance against environmental stresses. Their role in mitigating drought, salinity, heat stress, and nutrient imbalance has become increasingly significant under climate change scenarios. However, excessive or improper application may adversely affect plant metabolism and environmental safety, emphasizing the need for scientific and judicious use of these compounds. Therefore, understanding the mechanisms, applications, and agronomic importance of plant growth regulators is essential for achieving sustainable crop production and food security. This article highlights

major types, physiological functions, and practical applications of PGRs in modern agriculture along with their potential benefits and limitations in crop production systems.

Types of Growth Regulators

Growth regulators are classified into five major groups based on their functions and chemical nature:

1. **Auxins:** Promote cell elongation, root initiation, and differentiation. Commonly used for fruit setting and weed control.

2. **Gibberellins:** Stimulate stem elongation, seed germination, and flowering. Used to increase fruit size and break seed dormancy.

3. **Cytokinins:** Promote cell division and delay leaf senescence. Useful in tissue culture and enhancing grain yield.

4. **Ethylene:** Involved in fruit ripening and leaf abscission. Applied to synchronize fruit ripening and induce flowering in some crops.

5. **Abscisic acid (ABA):** Regulates stress responses and stomatal closure, helping plants tolerate drought conditions.

Mechanism of Action

Growth regulators act by interacting with specific receptors in plant cells, triggering a cascade of biochemical and molecular responses that alter gene expression and enzyme activities. This results in modified physiological outcomes, such as enhanced growth or improved stress resistance. Regulation is highly concentration-dependent, and the timing of application is critical to achieving desired results (Taiz and Zeiger, 2010).

Applications in Crop Production

1. **Improving Crop Yield:** Auxins and cytokinins, when applied exogenously, stimulate flowering, fruit development, and grain filling, leading to increased yield. For example, gibberellins are widely used in grapes to enhance berry size.

2. **Controlling Plant Growth:** Plant height can be regulated by growth retardants, a class of PGRs that inhibit gibberellin biosynthesis. This leads to sturdy and lodging-resistant

1. crops such as cereals.

2. **Enhancing Stress Tolerance:** ABA and some cytokinins improve plant tolerance to drought, salinity, and cold by regulating stomatal closure and antioxidant activities.

3. **Seed Germination and Dormancy:** Gibberellins break seed dormancy and promote uniform germination, which is critical for crop establishment.

4. **Fruit Ripening and Quality:** Ethylene is used commercially to synchronize the ripening of fruits like tomatoes and bananas, improving marketability and post-harvest life.

Advantages and Limitations

The use of growth regulators in agriculture offers numerous benefits, including improved yield, better crop quality, and efficient resource use. They can reduce the need for chemical inputs and enhance sustainable farming practices. However, challenges remain, such as the correct dosage, risk of phytotoxicity, environmental persistence, and variable effectiveness under field conditions. Integrated management practices and continued research are essential for optimizing the use of PGRs.

Conclusion

Growth regulators are indispensable tools in crop production, offering diverse applications to manipulate plant growth and development effectively. Their strategic use can significantly contribute to achieving food security and sustainable agriculture goals. Future developments in biotechnology and molecular biology are expected to unlock new potentials for growth regulators, paving the way for precision agriculture.

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