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SOWING THE FUTURE OF FOOD

Every towering stalk of maize, every heavy head of wheat, and every vibrant field of cotton that stretches across our horizons begins exactly the same way: as a silent promise packed into a tiny, unassuming casing. Seeds are the ultimate technology. They are nature's data storage units, holding thousands of years of evolutionary wisdom, climate adaptation, and genetic potential in a package small enough to hold in the palm of your hand.

Too often, when we talk about the future of farming, our conversations gravitate toward the massive and the visible—automated autonomous tractors, high-resolution satellite imaging, and sprawling global logistics networks. But all the heavy machinery and digital data in the world mean very little without the precise biological spark that starts the entire agricultural lifecycle. Seeds are the literal and figurative core of global food security, acting as the foundation upon which all human civilization is built.

Right now, the seed sector is undergoing a profound and rapid transformation. Breeders and researchers are locked in a high-stakes, frantic race against an increasingly volatile and unpredictable climate. As shifting weather patterns, prolonged droughts, and novel pest pressures threaten historic crop yields, the demand for resilient varieties has never been more urgent. Today, cutting-edge gene editing is actively unlocking unprecedented drought tolerance, while dedicated heirloom varieties are being meticulously preserved across global seed banks for their robust, irreplaceable genetic diversity. Simultaneously, modern supply chains are being redesigned to ensure these vital inputs reliably reach the world's smallholder farmers just in time for the critical planting window.

We are also witnessing a fascinating shift in the underlying economics of the seed industry. From the grassroots rise of local, independent seed entrepreneurs to the highly complex, ongoing debates surrounding intellectual property rights and seed sovereignty, the landscape is shifting. The tough choices being made in laboratory cleanrooms and corporate boardrooms today will directly dictate what lands on our dinner tables tomorrow.

As you read through this special issue, we invite you to look at the humble seed with renewed awe. It is not just the starting point of a single season; it is an incredible capsule of human ingenuity, ecological resilience, and enduring hope for the future.

Wishing you a season of abundant growth.

Rajni Shaleen Chopra

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From the CEO's desk

Small Seeds, Big Futures

At the heart of every harvest lies a quiet beginning—the seed. Small, often overlooked, yet profoundly powerful, seeds embody both resilience and possibility. They are not merely inputs in agriculture; they are the carriers of heritage, innovation, and the future of food systems. Within each seed rests a story of survival and adaptation, shaped by nature and nurtured by human ingenuity over generations. In many ways, seeds are the most compact expression of life's continuity.

In today's rapidly evolving agricultural landscape, the significance of seeds has expanded far beyond germination. They represent years of scientific research, traditional wisdom, and adaptive strategies designed to confront climate uncertainty. From drought-tolerant and pest-resistant varieties to biofortified crops that address nutritional gaps, seeds are emerging as the frontline response to some of the most pressing challenges facing global agriculture. Their role is no longer passive; it is deeply transformative and increasingly strategic.

India's agricultural journey offers a compelling testament to the power of seeds. The Green Revolution, driven by improved seed varieties, reshaped the nation's food security narrative and lifted millions out of scarcity. Today, a new revolution is underway—one that integrates advanced technology, sustainability, and farmer-centric innovation. Hybrid development, precision breeding, and biotechnology are accelerating productivity, while indigenous seed conservation efforts are safeguarding genetic diversity and cultural heritage. Together, they reflect a dual commitment to progress and preservation.

Equally significant is the role of farmers as custodians of seeds. Across regions, farming communities continue to preserve native varieties, ensuring biodiversity and ecological balance. These traditional seeds, often more resilient to local climatic stresses, are invaluable in building sustainable and climate-resilient agricultural systems. Their coexistence with modern hybrids presents not a contradiction, but a complementary and balanced pathway forward—one that respects both science and tradition.

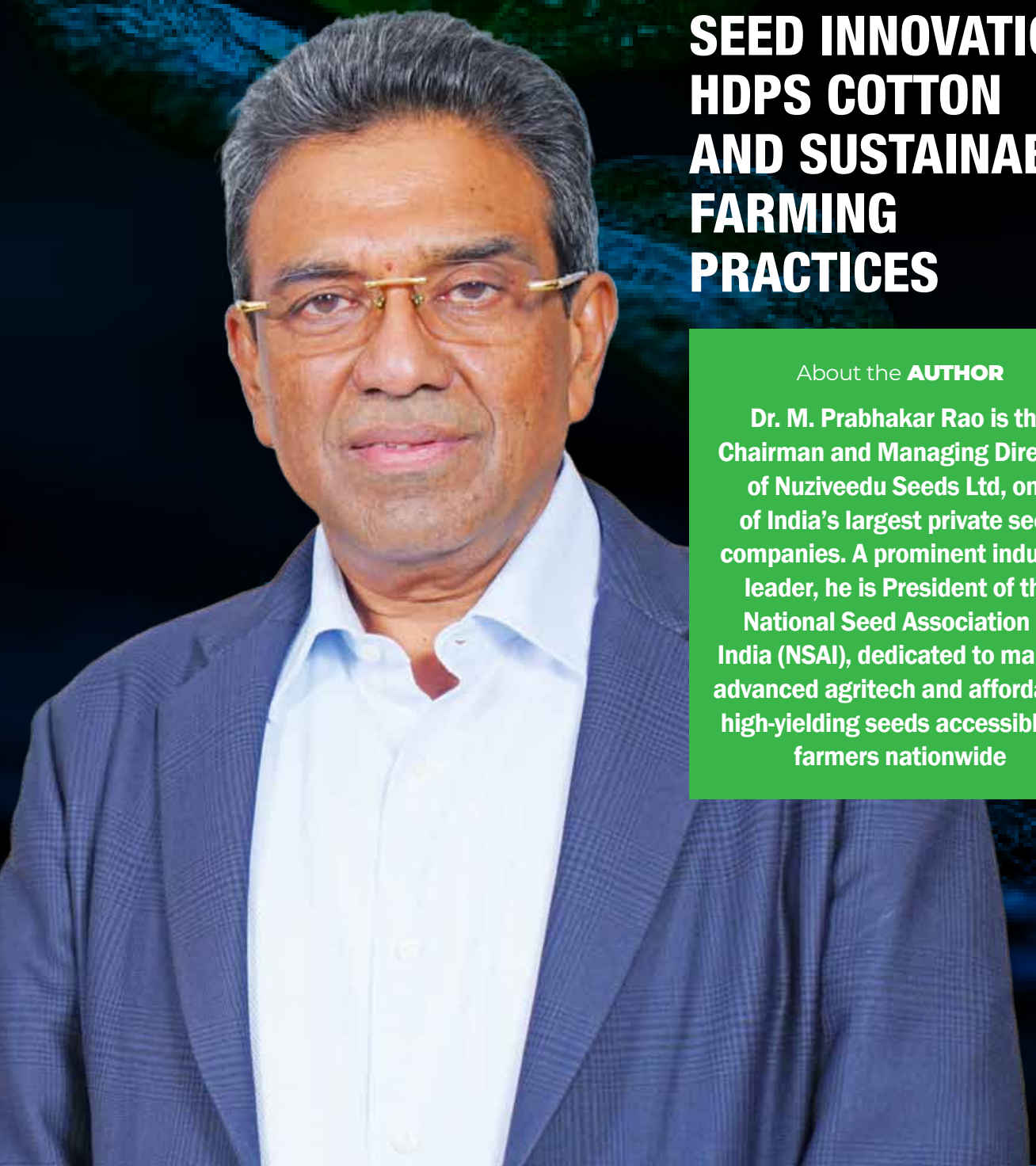
Yet, the journey is not without its complexities. Questions around seed accessibility, affordability, intellectual property rights, and equitable distribution remain central to policy discourse. Bridging the gap between innovation and access is essential to ensure that the benefits of seed advancements reach every farmer, regardless of scale or geography. Strengthening seed systems will be key to achieving truly inclusive growth.

Seeds are stories—of science and soil, of tradition and transformation, of challenge and hope. They remind us that every agricultural success begins with a choice: what we plant today will define the harvests of tomorrow. In nurturing seeds, we are, in essence, nurturing the future itself..

Haris Khan

Transforming INDIAN AGRICULTURE

SEED INNOVATION, HDPS COTTON AND SUSTAINABLE FARMING PRACTICES



About the **AUTHOR**

Dr. M. Prabhakar Rao is the Chairman and Managing Director of Nuziveedu Seeds Ltd, one of India's largest private seed companies. A prominent industry leader, he is President of the National Seed Association of India (NSAI), dedicated to making advanced agritech and affordable, high-yielding seeds accessible to farmers nationwide

Indian agriculture is entering a transformative phase where innovation, sustainability, technology, and policy reforms are collectively reshaping the future of farming. As the country works towards ensuring food and nutritional security for a growing population amidst climate uncertainties, the role of quality seeds and scientific agricultural practices has become more critical than ever. Today, the seed industry is not merely supplying planting material; it is emerging as a strategic partner in driving productivity, resilience, and farmer prosperity.

Over the years, the Indian seed sector has evolved significantly through advancements in plant breeding, biotechnology, precision agriculture, and integrated crop management. Farmers are increasingly adopting high-yielding hybrids and improved varieties that offer better tolerance against pests, diseases, and climatic stresses. At the same time, the sector is witnessing rapid changes driven by supportive government policies, agri-tech innovations, biological inputs, mechanization, and digital agriculture solutions.

However, agriculture continues to face multiple challenges including erratic weather conditions, water scarcity, declining soil health, rising cultivation costs, and labour shortages. Addressing these challenges requires integrated solutions that combine superior genetics, sustainable farming systems, technology adoption, and farmer education.

High Density Planting System (HDPS) in Cotton Cultivation

At Nuziveedu Seeds Limited (NSL), we strongly believe that the future of Indian agriculture lies in combining innovation with sustainability and farmer-centric development. Our commitment has always been to empower farmers with high-performing seed technologies and modern agronomic practices that improve productivity, profitability, and climate resilience.

One of the most promising advancements in recent years has been the increasing adoption of the High-Density Planting System (HDPS) in cotton cultivation. HDPS is a scientific cultivation approach where cotton is grown at closer spacing using compact hybrids to achieve higher plant population per acre. This system allows optimum utilization of sunlight, water, nutrients, and land resources, resulting in improved crop productivity and better farm economics.

One of the most promising advancements in recent years has been the increasing adoption of the High-Density Planting System (HDPS) in cotton cultivation

The advantages of HDPS are substantial. Farmers benefit from early crop maturity, better boll distribution, improved nutrient-use efficiency, efficient pest management, and suitability for mechanized operations. More importantly, HDPS helps achieve higher yields with balanced input usage, making cotton cultivation more sustainable and profitable.

Recognizing its transformative potential, NSL has taken a proactive role in promoting HDPS among cotton farmers across various regions. We have introduced specially developed cotton hybrids suitable for HDPS conditions, ensuring better adaptability, uniform growth, and stable performance. Through extensive field demonstrations, farmer meetings, technical training programs, and agronomic guidance, our teams actively educate farmers on optimum spacing, nutrient management, irrigation practices, and integrated pest management essential for successful HDPS cultivation.

Direct Seeded Rice

Another important practice shaping sustainable agriculture is Direct Seeded Rice (DSR), which is gaining importance as an alternative to conventional paddy transplantation. Traditional rice cultivation consumes large quantities of water and labour, making it increasingly difficult under present-day resource constraints. DSR offers an efficient and resource-conserving solution by enabling direct sowing of rice seeds into the field without transplantation.

DSR significantly reduces water usage, lowers labour dependency, minimizes cultivation costs, and shortens crop duration. It also contributes to environmental sustainability by reducing methane emissions and improving soil structure. As water conservation becomes a national priority, DSR is emerging as a critical technology for future rice sustainability.

NSL has been actively promoting DSR practices through farmer awareness campaigns, field demonstrations, and technical support. Our teams guide farmers on land preparation, weed management, seed treatment, nutrient scheduling, and irrigation management necessary for successful DSR adoption.

The growing acceptance of DSR reflects the increasing need for climate-smart and resource-efficient farming systems.

Beyond HDPS and DSR, the broader agricultural ecosystem in India is also undergoing rapid transformation. Policy reforms aimed at improving seed quality, enhancing traceability, strengthening intellectual property systems, and encouraging private sector participation are creating new opportunities for innovation and investment in agriculture.

Other Major Developments Transforming The Agricultural Sector

The rise of agri-tech startups is bringing fresh energy into the sector through digital advisory platforms, precision farming tools, drone technologies, remote sensing, supply chain innovations, and farm mechanization services. Farmers today are increasingly benefiting from real-time advisory systems, weather forecasting tools, mobile-based applications, and AI-driven decision support systems that improve farm efficiency and reduce risks.

Artificial Intelligence and data-driven agriculture are expected to play a major role in the future of farming. Predictive analytics, satellite-based crop monitoring, soil intelligence systems, and precision input management are helping farmers make informed decisions while optimizing productivity and sustainability. Such technologies are gradually transforming agriculture from intuition-based practices to knowledge-driven farming systems.

The future of Indian agriculture will depend on our ability to balance productivity with sustainability, innovation with inclusiveness, and growth with environmental responsibility

Mechanization is another key trend accelerating agricultural efficiency. Farm machinery suitable for small and medium landholdings, precision sowing equipment, mechanical harvesters, and drone-based spraying technologies are improving labour efficiency and operational productivity. Practices like HDPS are also enabling greater compatibility with mechanized farming systems.

Simultaneously, there is growing interest in biologicals and bio-inputs including bio-fertilizers, bio-stimulants, and bio-pesticides. Farmers are increasingly adopting sustainable crop nutrition and crop protection solutions that improve soil health while reducing chemical dependency. The integration of biological solutions with quality seed technologies will become increasingly important for sustainable agriculture in the coming years.

India Possesses Immense Potential In Seed Exports And Global Agricultural Trade

India also possesses immense potential in seed exports and global agricultural trade. With diverse agro-climatic conditions, strong scientific capabilities, and expanding research infrastructure, the country can emerge as a major global hub for seed production and agricultural innovation. Strengthening seed quality systems and regulatory frameworks will further enhance India's competitiveness in international markets.

At NSL, our role extends beyond seed production. We see ourselves as partners in agricultural transformation and farmer empowerment. Through continuous investment in research, farmer outreach programs, sustainable farming initiatives, and innovative crop solutions, we remain committed to supporting a resilient, productive, and future-ready agricultural ecosystem.

The future of Indian agriculture will depend on our ability to balance productivity with sustainability, innovation with inclusiveness, and growth with environmental responsibility. By promoting advanced practices such as HDPS and DSR alongside superior seed technologies and modern agricultural solutions, NSL aims to contribute meaningfully towards building a prosperous and sustainable future for Indian farmers and agriculture.

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THE STRUCTURAL TRANSFORMATION OF INDIA'S SEED ECOSYSTEM

India's Moment To Lead The Global Seed Revolution

India's seed and agriculture ecosystem stand at a defining moment. Over the past three to five years, a combination of policy reforms, scientific advancement, and institutional momentum has set the stage for a structural transformation that could reshape not only domestic agriculture, but India's position in global agricultural trade. What we are witnessing is not incremental change, but the early contours of a new paradigm, one that is innovation-driven, climate-aware, and globally competitive.

At the heart of this transformation lies a strong policy push. The government has introduced far-reaching reforms and new guidelines that streamline approvals for biotechnology, significantly improving the ease of innovation. These changes are not merely procedural; they directly impact the speed at which scientific breakthroughs can reach farmers' fields. At the same time, digital governance tools such as the SATHI traceability portal are laying the groundwork for a more transparent and efficient seed ecosystem. Yet, despite these gains, regulatory fragmentation across states continues to impose significant costs. Redundant testing and inconsistent licensing frameworks are estimated to cost the industry over Rs 800 crore annually. A unified, digitally enabled regulatory architecture could unlock savings of Rs 382–708 crore each year, while also accelerating research and development.

Science And Innovation Are Reshaping The Sector In Tangible Ways

Science and innovation are already reshaping the sector in tangible ways. Hybrid seeds remain the backbone of India's productivity gains. Today, similar advances are being extended across crops such as maize, vegetables, and oilseeds. The

About the **AUTHOR**

Mr Ajai Rana is Chairman, Federation of Seed Industry of India (FSII) and CEO & MD, Savannah Seeds

emergence of genome editing marks the next frontier. India's approval of field trials for genome-edited rice varieties, DRR 100 and Pusa DST1, signals a progressive regulatory stance. These CRISPR-based innovations offer higher yields, shorter maturity cycles, and resilience to salinity and drought, all while reducing input requirements. Importantly, the exemption of SDN-1 and SDN-2 edits from full GMO review has significantly shortened approval timelines, enabling faster deployment of climate-resilient solutions.

Equally transformative is the integration of digital agriculture. The Digital Agriculture Mission is building a robust data backbone through initiatives such as AgriStack, which is issuing approximately 10.8 crore Farmer IDs linking land, livestock, and crop data. Platforms like the Krishi Decision Support System are integrating satellite imagery, soil data, and government schemes to deliver precise, field-level advisories. The scale of adoption is already evident. The Kisan e-Mitra voice bot has handled over 93 lakh farmer queries as of December 2025, while the National Pest Surveillance System, launched in 2024, is being used by more than 10,000 extension workers to identify crop threats through image-based diagnostics. These tools are not just technological add-ons; they are redefining how farmers access knowledge and manage risk.

India's Seed Industry Needs Right Policy Support And Sustained Investment In Innovation

From a market perspective, the opportunity is immense. India's seed market, valued at approximately Rs 35,000 to Rs 40,000 crore by 2025, is already the fifth largest globally. Yet, its share in global seed trade remains at just about 1%. With the right policy support and sustained investment in innovation, this can change dramatically. Industry projections suggest that India could capture nearly 10 percent of global seed trade by 2035. A near-term milestone of achieving $1.4 billion, or roughly Rs.10,000 crore, in seed exports by 2028 has already been articulated. India has established strengths in vegetable

Industry projections suggest that India could capture nearly 10 percent of global seed trade by 2035. A near-term milestone of achieving $1.4 billion, or roughly Rs.10,000 crore, in seed exports by 2028 has already been articulated. India has established strengths in vegetable and spice seeds and is steadily expanding its footprint in cereals and pulses

and spice seeds and is steadily expanding its footprint in cereals and pulses.

An equally important dimension of this export opportunity lies in the evolving landscape of genetically modified (GM) technologies. Globally, GM crops, particularly maize, dominate seed trade due to their proven gains in yield, pest resistance, and input efficiency. India, with its strong hybrid seed production ecosystem, favourable agro-climatic zones for seed multiplication, and cost competitiveness, is well positioned to emerge as a reliable export hub for GM crop seeds, especially for markets in Southeast Asia, Africa, and Latin America. While domestic policy on GM crop cultivation remains calibrated, enabling a clear and facilitative framework for GM seed production strictly for export could unlock significant value.

India, with its strong hybrid seed production ecosystem, favourable agro-climatic zones for seed multiplication, and cost competitiveness, is well positioned to emerge as a reliable export hub for GM crop seeds, especially for markets in Southeast Asia, Africa, and Latin America. While domestic policy on GM crop cultivation remains calibrated, enabling a clear and facilitative framework for GM seed production strictly for export could unlock significant value

Indian Farmers Are Increasingly Embracing Innovation

The most encouraging signal, however, comes from the ground. Indian farmers are increasingly embracing innovation and actively seeking access to advanced technologies. In regions facing climate stress, such as the semi-arid Indo-Gangetic belt, new heat- and drought-tolerant rice varieties are being tested and adopted. In water-scarce states like Punjab and Haryana, direct-seeded rice is emerging as a viable alternative to traditional transplanting, offering significant savings in water and labor while reducing greenhouse gas emissions. These shifts reflect a deeper change in farmer behaviour—from risk aversion to informed experimentation.

Sustainability is no longer an adjunct objective; it is central to the sector's evolution. Advances in seed technology, whether through hybrids or genome editing, are enabling higher productivity with fewer inputs, aligning agricultural growth with environmental imperatives. New rice varieties that shorten crop duration can reduce methane emissions from flooded fields, while improved maize and pigeonpea hybrids are better equipped to withstand erratic weather patterns. Precision agriculture tools, including sensors, drones, and AI-based advisory systems, are enhancing input efficiency and reducing wastage. Expanded soil health mapping, covering 29 million hectares as of September 2024, further strengthens the foundation for sustainable intensification.

If these elements come together, India can move from being a large domestic market to a global powerhouse in seed innovation and trade. The stakes are high, but so is the opportunity. At its core, this is about enabling farmers with the best tools science can offer, ensuring food security in a climate-constrained world, and contributing to the vision of a Viksit Bharat.

BIOTECH AND AI ARE REDEFINING THE MODERN CROP

A revolution is taking place in the seed and agriculture ecosystem, driven by technological progress, sustainability demands, new policies, and market conditions. Seeds play an important role in agriculture and are at the heart of this revolution, setting the pace for efficiency and sustainability. Some of the main innovations include bio-tech, smart farming, and regulation systems.

The most prominent of these are the tremendous advances that have occurred in seed biotechnology. Seeds account for up to 90 percent of the global produce of agricultural crops, making them very important in terms of agricultural productivity. In the last decade, genome editing with technologies such as CRISPR, hybridization, and biofortification have been used successfully in developing highly productive and disease resistant as well as nutritious seeds. Genome editing is done in order to develop plants that are more disease-resistant and capable of surviving in drought-like situations. Biofortification is performed to solve malnutrition issues.

Novel techniques like synthetic seeds and nanotechnology-assisted seed priming are being utilized as well. With the help of synthetic seeds, elite plants as well as rare plant species can be multiplied and conserved. In addi-

About the **AUTHOR**

Mr Amit Saraogi, founder of Anmol Feeds, is a visionary entrepreneur revolutionizing India's feed industry with innovation, uncompromising quality, sustainable growth, and customer trust

tion, nanotechnology helps to enhance germination ability and stress tolerance as well. These advancements in technology have led to enhanced efficiency and sustainable production, enabling farmers to yield maximum output with limited inputs.

Emergence Of Digital And Precision Agriculture

Along with advances in seed technology, there is a total revolution taking place in the agricultural domain because of the emergence of digital and precision agriculture. Artificial intelligence (AI), IoT, drone technology, and remote sensing are some of the technologies that are helping in creating an intensive farming practice based on data. Precision agriculture has the capacity to reduce water use by about 20 to 40 percent and fertilizer usage by 30 percent, along with boosting agricultural production efficiency.

Institutional, ecosystemic, and socio-cultural elements are essential when it comes to shaping the course of the ongoing changes within the seed and agriculture sector

Evidence from some modern initiatives can highlight the growing significance of AI and data analytics in agriculture. On the one hand, there have been research studies involving the use of artificial intelligence and genomics in enhancing efficiency and disease resistance of plants. This includes the use of supercomputers and their application on the farm level. On the other hand, there is also an initiative called "cluster AI farming" that aims at using modern technology in providing recommendations for farmers on water, fertilizers, and pests.

Climate-Smart And Sustainable Agriculture

An important trend influencing the ecosystem is that of climate-smart and sustainable agriculture. This type of agriculture is both an outcome and a victim of climate change, hence the push towards more environmentally friendly forms of farming. There is an increasing trend towards innovations like carbon sequestration and the use of crop varieties that are climate resilient. Not only do these farming techniques enhance the resilience of the ecosystem, but they also play a role in the reduction of global carbon emissions.

There is also increasing interest in vertical farms and controlled environments within the domain of sustainable agriculture. They can deliver 10 to 20 times higher productivity with much lower water usage, making them especially pertinent for urban and resource-limited locations. It involves moving away from conventional farming practices which involve large amounts of land usage.

Policy Support

Institutions and policies play an equally vital role in developing the seeds and agriculture industry. There has been an increased awareness on the part of governments about the significance of seed technology and agriculture advancements. For instance, in India, there have been attempts to promote high-yielding seeds through the National Mission on High Yielding Seeds, and speed breeding and gene-editing technologies are being considered. Nevertheless, obstacles still persist, among which is the lack of private funding.

The ecosystem is also being shaped through collaborative and innovation

platforms. With global programs and hackathons, there is an increasing effort to develop AI-enabled innovations for farming, which involve startups, researchers, and youth. Through such platforms, innovation and openness are encouraged, allowing for quick innovation and implementation of new technologies, especially in areas such as climate resilience and supply chain efficiency.

Challenges In Terms Of Biotechnology And Biodiversity

On the other hand, the seed ecosystem faces challenges in terms of biotechnology and biodiversity. GM seeds and gene-edited seeds provide many advantages in terms of productivity and resilience, but they also pose threats to the environment, corporate dominance, and the extinction of local seeds. There have been efforts to promote seed sovereignty and preserve indigenous seeds.

Technology integration within agriculture involves the integration of seeds, data, climate-smart techniques, and policy

One significant development in this regard is the revolution that is being seen in the value chain of agriculture as well as the role of the farmer. As a result of technological advancements, there has been a change in the farmer's role whereby the farmer is now operating as a manager of complex data-driven systems instead of just being a laborer.

Technology Integration

Lastly, there has been the emergence of greater attention to be paid to integration within the ecosystem as well as data-driven decision making. Technology integration within agriculture involves the integration of seeds, data, climate-smart techniques, and policy. In spite of these positive changes within agriculture, some challenges will still have to be overcome before the true potential can be unlocked.

To conclude, the trends that have been witnessed in the seed and agriculture industry are multi-faceted and interconnected. The advancements in seed biotechnology, digital agriculture, and sustainability have led to the emergence of more efficient food production. At the same time, it must be highlighted that institutional, ecosystemic, and socio-cultural elements are essential when it comes to shaping the course of the ongoing changes within the seed and agriculture sector. With global population growth on the rise and increasing environmental challenges, these issues will become increasingly important.

HYFUN FOODS, ADANI LOGISTICS AND EVERGREEN MARINE CORP INTRODUCE ECO-FRIENDLY EXPORT CORRIDOR

HyFun Foods has stepped into sustainable export Logistics and has launched a new reefer rail transport initiative in collaboration with Adani Logistics and Evergreen Marine Corporation.

This first ever dedicated Reefer Rail for HyFun's frozen potato products is replacing up to 40 road trips per shipment, enhancing supply chain efficiency, reducing fuel consumption and lowering carbon footprint.

This initiative is not only complementing but also completing the integrated multimodal (road, rail & Sea) logistics system thanks to the infrastructure development by the Government of India in the past few years.

In a significant step aligned with Prime Minister Narendra Modi's recent call to reduce India's consumption of fuels and adopt more sustainable modes of transportation, HyFun Foods, a pioneer in the exports of frozen potato products, has taken a landmark tripartite initiative with Adani Logistics Ltd. and Evergreen Marine Corporation to create a seamless and environmentally responsible export logistics corridor.

The initiative introduces a dedicated rail freight solution for the transportation of HyFun Foods' frozen products for export. Each such train movement is expected to replace 40 road trips, substantially reducing fuel consumption, road congestion and carbon emissions while ensuring reliable and temperature-controlled movement of products.

The train has been exclusively deployed for the transportation of HyFun Foods' products and will operate from Virochannagar ICD to Mundra Port, part of the integrated logistics ecosystem operated by Adani Ports and SEZ Ltd. (APSEZ), with onward exports handled by Evergreen Marine Corporation, creating an integrated export corridor. The inaugural run of the dedicated reefer rail service was flagged off on May 21, 2026.

Efficient And Sustainably Reliable Export Operations

Regarding the development, Mr Kamlesh Karamchandani, Group Executive Director, HyFun Foods, mentioned, "Today, HyFun Foods exports to more than 40 countries

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across global markets, and this collaboration will further strengthen our export capabilities by enabling more efficient, and sustainably reliable export operations. As we continue to scale our global footprint, this initiative will play an important role in supporting our ambition to expand our presence to over 100 countries in the coming years."

Mr Haresh Karamchandani, Group CEO and Managing Director, HyFun Foods, stated, "We are deeply grateful to Adani Logistics Limited and Evergreen Marine Corporation for their partnership and support in bringing this wonderful initiative to life. This initiative will give boost to our endeavour of taking the hard work of Indian farmers to the world by transforming their produce into value-added frozen food products, thereby increasing their incomes."

Mr Naresh Kapoor, Chief Supply Chain Officer, HyFun Foods, stated, "As a leader in the frozen food industry, HyFun Foods has always remained committed to advancing its sustainability initiatives and environmental stewardship through meaningful action. This initiative marks our first dedicated step towards integrating sustainability into our export operations."

HyFun Foods is one of India's leading manufacturers and exporters of frozen potato products. With a strong presence in domestic and international markets, the company supplies premium-quality products to global quick-service restaurant chains, retail consumers and food-service partners. HyFun Foods is committed to innovation, sustainability and delivering world-class food solutions.

Mr Kamlesh Karamchandani is the dynamic Executive Director of HyFun Foods, a trailblazer in the global frozen food industry. Since the company's founding in 2015, Mr Kamlesh Karamchandani has been the driving force behind its remarkable 20X growth, leading HyFun to achieve a revenue milestone of 1000 Crores by 2023. Under his visionary leadership, HyFun has expanded its presence to over 40 countries and has become the undisputed leader in frozen French Fries exports from India, supporting the country's goal of self-sufficiency.

Mr Kamlesh Karamchandani's strategic foresight has propelled HyFun into key global markets, with the company now serving major international QSR chains like Burger King, KFC, Subway, Pizza Hut, etc. Domestically, HyFun has established a footprint in 300 cities across India, catering to the Food Service sector while also making significant inroads into the consumer-packaged goods market, reaching all eight metro cities and major e-commerce platforms.

"Today, HyFun Foods exports to more than 40 countries across global markets, and this collaboration will further strengthen our export capabilities by enabling more efficient, and sustainably reliable export operations."

Mr Kamlesh Karamchandani, Group Executive Director, HyFun Foods

A New Era IN SEED AND AGRICULTURAL ECOSYSTEMS

India's agricultural landscape is undergoing a profound transformation, with the seed ecosystem at the center of this evolution. Contributing nearly 15–16% to national GDP and supporting over 40–45% of the workforce, agriculture remains the backbone of rural livelihoods and economic stability. Today, a convergence of technology, sustainability, and evolving market dynamics is reshaping how the sector operates—creating both opportunities and responsibilities across the value chain.

Technological Transformation in Indian Agriculture

Indian agriculture is steadily transitioning from traditional practices to more technology-driven systems. Precision agriculture tools such as drones, IoT-enabled soil sensors, and satellite-based monitoring are enabling farmers to optimize input use and improve productivity.

About the **AUTHOR**

Mr Gubba Kiran, CEO of Gubba Cold Storage, has been leading the company into efficient service in cold storage preservation. Mr Gubba Kiran has virtually become the face of Gubba to the Indian seed industry. He has been the key driver in educating pharma companies about preserving the critical products at Gubba. He has also been instrumental in creating Gubba from 0.7 million cubic feet to one of India's biggest cold storage companies with 11 million cubic feet. He is inspired to make a difference to people through his study of Ontology

This transformation is reflected in output trends. India's foodgrain production has grown significantly over the past decade, supported by improved seed technologies and scientific agronomic practices. Artificial intelligence and predictive analytics are further strengthening farm-level decision-making—enabling farmers to anticipate weather variability, pest outbreaks, and nutrient requirements with greater accuracy.

Biotechnology is another key enabler. Advances in molecular breeding and genome editing are supporting the development of high-yielding and climate-resilient hybrids suited to India's diverse agro-climatic conditions. The seed ecosystem plays a critical role in ensuring that these innovations move efficiently from research to real-world application.

Sustainability as a Core Imperative

Sustainability is no longer optional—it is central to the future of Indian agriculture. Increasing climate variability, erratic rainfall, and rising temperatures are directly impacting productivity and farm incomes.

In response, the sector is witnessing a gradual shift toward more resilient and resource-efficient practices. Soil health management, water-use optimization, and reduced chemical dependency are becoming key focus areas.

Equally important is the development of seed varieties that perform consistently under stress conditions such as drought or salinity, while requiring fewer inputs. These advancements are

Government initiatives continue to play a key role in shaping the future of Indian agriculture. Investments in infrastructure, research, and seed systems are creating an enabling environment for growth and modernization

essential for balancing productivity with environmental responsibility.

With a significant portion of India's cultivated land still dependent on rainfall, improving water-use efficiency remains critical. The future lies in enabling "more crop per drop" through a combination of genetic innovation and better agronomic practices.

India's Expanding Agricultural Economy

India continues to strengthen its position as a global agricultural leader. It is among the largest producers of key commodities and has seen steady growth in agricultural exports over recent years.

This expansion reflects a broader shift toward commercialization and value-chain integration. Agriculture today extends beyond production to include processing, storage, logistics, and distribution—creating a more interconnected ecosystem.

Looking ahead, the sector holds significant growth potential, driven by infrastructure development, innovation, and stronger market linkages. The seed

industry will remain foundational to this growth by enabling consistency, quality, and adaptability across regions.

Changing Consumer Preferences and Market Dynamics

Consumer behaviour is increasingly influencing agricultural production systems. There is a growing demand for safe, traceable, and sustainably produced food. Greater awareness around nutrition and environmental impact is prompting shifts in both cultivation and supply chain practices.

Farmers and agri-businesses are aligning more closely with these expectations by focusing on quality, residue-free production, and improved shelf life.

Digital platforms are also transforming market access. Direct-to-consumer models and improved supply chain integration are enabling better price realization while reducing inefficiencies.

At the same time, traceability is becoming an important aspect of modern agriculture. Systems that track produce from seed to table are enhancing transparency and building consumer trust—encouraging a more accountable ecosystem.

Collaborative Ecosystems and Specialized Services

As agriculture becomes more complex and innovation-driven, the ecosystem is increasingly adopting a collaborative approach—similar to how global enterprises operate. In many ways, the sector is evolving to think and function like a Fortune 500 ecosystem, where specialized capabilities are leveraged through partnerships rather than built in isolation.

In this context, services such as multi-location trials (MLTs) and biotechnology lab support are becoming critical enablers for seed companies. These specialized functions require advanced infrastructure, technical expertise, and standardized processes to deliver reliable outcomes across diverse geographies.

Organizations like Gubba are contributing to this ecosystem by providing such specialized, research-driven services—supporting companies in evaluating seed performance across locations and strengthening quality and biotechnology capabilities. This model allows the broader industry to focus on core innovation while ensuring that critical support systems are managed with consistency and scale.

At the same time, public-private collaboration is becoming increasingly important in bridging the gap between research and field-level implementation. These partnerships are critical in addressing challenges such as climate resilience, productivity improvement, and farmer income stability

Such collaborative frameworks are essential for accelerating innovation and ensuring that advancements reach farmers effectively.

Policy Support and the Road Ahead

Government initiatives continue to play a key role in shaping the future of Indian agriculture. Investments in infrastructure, research, and seed systems are creating an enabling environment for growth and modernization.

At the same time, public-private collaboration is becoming increasingly important in bridging the gap between research and field-level implementation. These partnerships are critical in addressing challenges such as climate resilience, productivity improvement, and farmer income stability.

Pivotal Moment

India stands at a pivotal moment in its agricultural journey. The path forward lies in aligning science, sustainability, and scalability to build a resilient and future-ready ecosystem.

By embracing innovation, strengthening seed systems, and fostering collaborative approaches, the sector can create a future where farmers are empowered, food systems are resilient, and agriculture continues to drive economic growth. The transformation is already underway. Through collective efforts and a shared vision, we can make a meaningful difference in shaping a stronger and more sustainable future for Indian agriculture.

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VEGETABLE SEEDS

CHALLENGES IN INTERNATIONAL SEED BUSINESS AND POLICY REFORMS TO STRENGTHEN THE INDIAN SEED SECTOR

The Indian seed sector has emerged as a critical component of agricultural development, contributing significantly to productivity, food security, and rural livelihoods. With increasing globalization, Indian seed companies—particularly in the vegetable segment—are exploring international markets. However, they face multiple challenges, including regulatory barriers, supply chains disruptions, intellectual property constraints, technological gaps, and infrastructural limitations. Here I would like to highlight the key challenges faced by Indian seed companies in the international vegetable seed business and evaluates the policy reforms required to strengthen the Indian seed sector. It argues that a combination of regulatory simplification, enhanced research and development (R&D), stronger intellectual property frameworks, and improved infrastructure is essential to position India as a global leader in the seed industry especially for the Global South.

Seeds are the fundamental input in agriculture, determining crop productivity, resilience, and quality. The vegetable seed segment, in particular, has gained prominence due to rising global demand for high-yielding and disease-resistant varieties. India is one of the robust and fast-growing seed markets globally, supported by diverse agro-climatic conditions and opportunities to produce all

About the **AUTHOR**

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kind of vegetable seed production.

Despite these advantages, Indian seed companies face significant constraints in accessing and competing in international markets. The global vegetable seed market is dominated by a few multinational corporations with advanced technologies and strong intellectual property protections. Consequently, Indian firms encounter structural, regulatory, and technological challenges that limit their global competitiveness. Addressing these issues requires comprehensive policy reforms to strengthen the domestic seed ecosystem and enhance export potential.

1. Overview of the Indian Seed Sector

The Indian seed sector comprises both public and private players, with the private sector accounting for a significant share in hybrid vegetable seeds. The sector has experienced rapid growth due to increased adoption of hybrids, improved farming practices, and rising demand for vegetables.

India's comparative advantages include:

- Diverse agro-climatic zones suitable for seed production
- Availability of skilled labor
- Lower production costs compared to developed countries

However, the sector is constrained by regulatory complexities, inconsistent quality control, and limited integration with global value chains. These factors become more pronounced in the context of international trade.

The international vegetable seed business offers significant opportunities for Indian seed companies, but these are accompanied by substantial challenges. Regulatory barriers, technological gaps, quality issues, and global competition limit the ability of Indian firms to compete effectively in international markets

2. Challenges in International Vegetable Seed Business

Regulatory and Phytosanitary Barriers

International trade in seeds is governed by stringent phytosanitary standards to prevent the spread of pests and diseases. Countries impose strict requirements related to seed health, certification, and traceability. Indian seed companies often struggle to comply with varying regulations across markets, leading to delays, increased costs, and occasional rejection of consignments.

The lack of harmonization between domestic and international standards further complicates export processes. Small and medium enterprises (SMEs), in particular, face difficulties in navigating complex regulatory frameworks.

Intellectual Property Rights (IPR) Constraints

The global seed industry is heavily influenced by intellectual property regimes that protect plant varieties and biotechnological innovations. Multinational corporations hold extensive patents on key traits, such as pest resistance and yield enhancement.

Indian companies face challenges in accessing proprietary germplasm and technologies due to:

- High licensing costs
- Limited domestic innovation in advanced breeding
- Weak enforcement of IPR in some jurisdictions

Although India has implemented the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, alignment with global IPR frameworks remains incomplete. This limits the ability of Indian firms to compete in high-value markets.

Technological and R&D Limitations

The development of competitive vegetable seeds requires substantial investment in R&D, including molecular breeding,

genomics, and biotechnology. While large Indian firms have made progress, many companies lack the resources and expertise to invest in cutting-edge technologies.

This results in a technological gap between Indian companies and multinational competitors, who invest heavily in innovation. Consequently, Indian firms often compete in lower-value segments of the market.

Quality Assurance and Traceability Issues

Consistency in seed quality is a critical requirement in international markets. However, challenges in quality control persist in India due to:

- Inadequate testing infrastructure
- Weak enforcement of certification standards
- Presence of spurious or substandard seeds

These issues undermine the credibility of Indian seed exports and reduce trust among international buyers.

Infrastructure and Supply Chain Constraints

Efficient seed production and export require robust infrastructure, including storage facilities, cold chains, and transportation networks. In India, infrastructural gaps lead to:

- Post-harvest losses
- Delays in delivery
- Increased logistics costs

Such inefficiencies reduce the competitiveness of Indian seed companies in global markets. ISTA accreditation labs infrastructure need to be expanded and spread across India including from the public sector too.

A forward-looking policy approach, combined with industry innovation and collaboration, will enable Indian seed companies to unlock their full potential and contribute to global food security and agricultural development.

Domestic Regulatory Fragmentation

The Indian seed sector is regulated by multiple authorities at the central and state levels. This leads to duplication of processes, delays in approvals, and increased compliance costs. The absence of a unified regulatory framework hampers the ease of doing business and discourages investment.

Intense Global Competition

The international vegetable seed market is dominated by a few large multinational corporations with strong distribution networks, brand recognition, and advanced technologies. Indian companies face significant challenges in competing with these firms, particularly in premium segments.

Climate Change and Production Risks

Seed production is highly sensitive to environmental conditions. Climate change has increased the frequency of extreme weather events, affecting seed yield and quality. This introduces uncertainty in supply and makes it difficult for Indian

companies to meet export commitments consistently.

Limited Market Intelligence and Branding

Indian seed companies often lack access to reliable market intelligence and global marketing strategies. Weak branding and limited presence in international markets restrict their ability to capture high-value opportunities.

To overcome these challenges, comprehensive policy reforms are required. These include regulatory simplification, enhanced R&D investment, improved infrastructure, and stronger quality assurance mechanisms. By addressing these issues, India can strengthen its seed sector and establish itself as a major player in the global seed industry

3. Policy Reforms to Strengthen the Indian Seed Sector

Regulatory Simplification

A unified national regulatory framework is essential to reduce duplication and improve efficiency. The introduction of a "One Nation, One Licence" system can streamline approvals and facilitate ease of doing business.

Strengthening Quality Control Mechanisms

Improving seed quality requires:

- Modernization of testing laboratories
- Digital traceability systems
- Strict enforcement of certification standards

Such measures will enhance the credibility of Indian seeds in global markets.

Promoting Research and Development

Government support for R&D is crucial to bridge the technological gap. Policy measures may include:

- Tax incentives for private sector investment
- Increased funding for public research institutions
- Promotion of collaborative research initiatives

Investment in advanced breeding technologies will enable Indian companies to develop competitive products.

Enhancing Intellectual Property Frameworks

Strengthening IPR protection is necessary to encourage innovation and attract investment. Policies should aim to balance the interests of breeders and farmers while aligning with international standards.

Infrastructure Development

Investment in infrastructure is essential to improve efficiency and reduce costs. This includes:

- Establishment of seed processing hubs
- Development of cold storage facilities
- Improvement of transportation networks
- Expand and spread the ISTA accreditation Labs including Public sector

Enhanced infrastructure will support both domestic and export-oriented seed production.

Export Promotion Strategies

The government should actively promote seed exports through:

- Trade agreements and market access initiatives
- Simplification of export procedures
- Provision of market intelligence and support services

India has the potential to become a global hub for seed production due to its favorable agro-climatic conditions and can be a leader for the global south.

Public–Private Partnerships

Collaboration between public institutions and private companies can accelerate innovation and technology transfer. Public–private partnerships can play a key role in developing climate-resilient and high-yielding varieties.

Capacity Building and Extension Services

Strengthening extension services will improve farmer awareness and adoption of quality seeds. Capacity-building programs can enhance the efficiency of the seed supply chain and ensure better outcomes.

Legal and Institutional Reforms

Reforms in seed laws should focus on improving transparency, ensuring quality, and protecting farmer interests. A balanced legal framework will support both industry growth and agricultural sustainability.

Focus on Climate-Resilient Agriculture

Policies should prioritize the development of climate-resilient seed varieties to address the challenges posed by climate change. This will ensure long-term sustainability and resilience of the seed sector.

Opportunities and Challenges

The international vegetable seed business offers significant opportunities for Indian seed companies, but these are accompanied by substantial challenges. Regulatory barriers, technological gaps, quality issues, and global competition limit the ability of Indian firms to compete effectively in international markets.

To overcome these challenges, comprehensive policy reforms are required. These include regulatory simplification, enhanced R&D investment, improved infrastructure, and stronger quality assurance mechanisms. By addressing these issues, India can strengthen its seed sector and establish itself as a major player in the global seed industry.

A forward-looking policy approach, combined with industry innovation and collaboration, will enable Indian seed companies to unlock their full potential and contribute to global food security and agricultural development.

INDIA'S SUMMER WHEAT PROCUREMENT SEASON

BALANCING FOOD SECURITY, QUALITY, AND CLIMATE CHALLENGES

About the **AUTHOR**

Mr Praveen Kewlani is Director, Kewlani Agro Industries Pvt. Ltd.

India's wheat procurement season, conducted between April and June, is one of the most strategically important phases of the country's food economy. Wheat is India's second-most consumed cereal after rice, and the country is expected to produce nearly 115–117 million tonnes during the 2025–26 crop year. Government agencies, led by the Food Corporation of India (FCI), procure wheat at the Minimum Support Price (MSP), fixed at Rs.2,585 per quintal for the current season with some states like Madhya Pradesh offering extra bonus. While procurement has traditionally focused on maintaining food security reserves and supporting farmer incomes, the broader role of procurement has expanded significantly.

Today, it directly influences flour supply, food inflation, processing efficiency, and the stability of India's packaged staples industry. Efficient wheat procurement plays a critical role in ensuring stable flour supply and minimizing disruptions across the food value chain, particularly as demand for processed wheat products continues to rise across urban and rural markets.

The Shift from Quantity to Quality Procurement

India's wheat procurement ecosystem is gradually evolving from quantity-focused buying to quality-focused selection, especially in premium milling segments. Flour millers and food processors are increasingly prioritizing grain quality parameters

such as protein content, grain hardness, moisture levels, and milling yield rather than simply focusing on procurement volumes. This transition reflects changing consumer preferences for better-quality atta, bakery products, and packaged staples.

Madhya Pradesh has emerged as a significant contributor to this shift because of the growing preference for Sharbati wheat, known for its higher protein content, golden grain texture, and superior flour quality. Over the last decade, Madhya Pradesh has strengthened its position as one of India's largest wheat-producing and procurement states, often competing closely with Punjab and Haryana. The state's wheat is increasingly preferred by premium flour brands and large millers due to its consistency and suitability for value-added food products. This trend is gradually reshaping procurement priorities across the industry.

Climate Risks and Procurement Pressures

Climate volatility has become one of the biggest risks for India's wheat economy. Wheat is highly sensitive to temperature increases during the grain-filling stage in March and April, and agricultural experts estimate that every 1°C rise in temperature can reduce national wheat production by nearly 4–5 million tonnes. Heatwaves during 2022 and 2023 sharply reduced yields across Punjab, Haryana, and Uttar Pradesh, while irregular rainfall damaged grain quality during harvesting.

Rising summer temperatures are making scientific storage, moisture control, and faster procurement cycles more important than ever for the wheat industry. Wheat harvested under extreme heat conditions faces greater risks of moisture damage, fungal contamination, and pest attacks if procurement and storage are delayed. Since procurement operations coincide with peak summer months, even short logistical delays can increase post-harvest losses and affect grain quality throughout the supply chain.

Madhya Pradesh's Growing Strategic Importance

The growing role of Madhya Pradesh in India's wheat economy reflects larger structural changes within procurement and milling markets. Unlike Punjab and Haryana, where procurement is heavily MSP-driven, Madhya Pradesh has increasingly attracted private millers and food processors due to the quality characteristics of its wheat. The state's central location also offers logistical advantages for supplying flour mills across western and southern India.

The future of wheat procurement will therefore depend not only on government buying capacity but also on how effectively the industry integrates quality management, technology adoption, and climate adaptation into its procurement strategy

In recent years, Madhya Pradesh has contributed significantly to national procurement volumes, supported by improved mandi infrastructure, warehouse expansion, and better transportation networks. However, challenges remain. Procurement systems in many states still suffer from uneven infrastructure, delayed lifting of grain from mandis, and insufficient scientific storage capacity. While procurement in traditional northern states remains dominant, expanding infrastructure in central and eastern India will be important for improving farmer access to MSP systems and reducing regional concentration risks.

Technology and Modern Storage Are Reshaping Procurement

Technology-led quality assessment and modern warehousing practices are gradually transforming traditional grain procurement systems in India. Automated moisture-testing equipment, digital grading systems, online farmer registration, and direct payment platforms are improving transparency and operational efficiency across procurement networks. At the same time, modern silos and scientific warehouse systems are helping reduce grain losses caused by heat, humidity, and poor handling practices. India still stores a significant portion of wheat in conventional storage systems, where exposure to moisture and temperature fluctuations can impact grain quality.

Investments in steel silos, temperature-controlled storage, and digital inventory tracking are therefore becoming increasingly important. For flour mills and food processors, technology is also enabling more consistent sourcing, better traceability, and improved quality control standards across procurement operations.

Building a More Resilient Wheat Ecosystem

India's wheat procurement system is entering a phase where long-term resilience will matter as much as procurement volume. Stronger collaboration between farmers, procurement agencies, and milling companies is becoming essential for improving long-term wheat quality and supply resilience.

Climate-resilient seed varieties, better irrigation systems, scientific storage, and accurate weather forecasting will all play a crucial role in protecting future wheat output. At the same time, procurement policies may need greater flexibility to respond to changing market conditions. As India's flour, bakery, and processed food sectors continue to expand, procurement efficiency will increasingly determine the stability of the broader food economy. The future of wheat procurement will therefore depend not only on government buying capacity but also on how effectively the industry integrates quality management, technology adoption, and climate adaptation into its procurement strategy.

QUICK COMMERCE IN AGRICULTURE
THE NEXT REVOLUTION IN DELIVERING INNOVATION TO INDIA'S FARMERS

About the **AUTHOR**

Mr Nitiin R Sonar is Chief Operating Officer – Manufacturing and Operations at Biostadt India Limited, a leading biotechnology and agricultural solutions company with a global presence operating across 22 countries. With over 28 years of core industry experience, he has been instrumental in the seamless and smooth functioning of multiple processes at Biostadt India Limited

Urban consumers today receive groceries in 10 minutes. Farmers in remote villages, however, still wait days—or sometimes even weeks—for critical agricultural inputs such as seeds, fertilizers, and crop protection products. The next agricultural revolution will not only happen in laboratories or on farms; it will happen in supply chains.

India has made tremendous progress in agricultural innovation through better seeds, advanced crop protection chemistry, and modern farming practices. Yet, one critical challenge continues to limit the full impact of these innovations: ensuring that these products reach farmers quickly, efficiently, and affordably—especially in rural and remote regions.

It is time for India's agricultural industry to embrace Quick Commerce (Q-Commerce) and digital supply chain transformation, inspired by the success of platforms like Blinkit and Zomato. By combining digital technology with decentralized physical infrastructure, we can dramatically improve access, reduce costs, and empower farmers like never before.

The Need to Rethink Traditional Distribution Models

The traditional agricultural distribution model has served the industry for decades, but it comes at a significant cost. Multiple layers—manufacturers, C&FA / Warehouse, super stockists, distributors and retailers—often make the supply chain inefficient and expensive. It is estimated that companies may spend nearly 20–30% of the product cost on distribution be-

fore the product finally reaches the farmer, including multiple transport and distributors and retailers' margins.

Beyond cost, these multiple touchpoints increase lead times, reduce visibility, and often create stock imbalances. Farmers frequently face product shortages during critical crop stages, even when stock is available elsewhere in the network.

To address this, Agro Seeds and Chemicals companies must come together and build a shared digital and physical ecosystem that enables faster, smarter, and more direct delivery of agricultural products.

India Has the Talent and Infrastructure to Lead This Change

India is uniquely positioned to lead this transformation.

The country possesses world-class digital talent capable of building advanced supply chain platforms for inventory visibility, order management, and real-time delivery tracking. At the same time, rural India is undergoing a digital revolution. In my own experience, I have observed that almost every farmer today owns a smartphone and is increasingly comfortable using digital tools.

Young farmers, in particular, are ready to adopt new technologies and are eager to participate in entrepreneurial opportunities. In many rural areas, almost every household owns a two-wheeler. These vehicles can become powerful assets in building a decentralized quick-commerce delivery network, generating large-scale local employment while solving the challenge of last-mile delivery.

Agro Seeds and Chemicals companies must come together and build a shared digital and physical ecosystem that enables faster, smarter, and more direct delivery of agricultural products

Imagine a system where local youth use their two-wheelers to deliver essential farm inputs within hours, directly from nearby Dark Stores / fulfillment centers to farmers in need. This would not only create employment but also strengthen rural economies.

Dark Stores at Taluka and Village Levels

One of the most promising solutions is the creation of "dark stores"—small, strategically located storage hubs dedicated to rapid order fulfillment.

Agricultural companies should collaborate to establish dark stores at taluka and even village levels, reducing dependency on multiple intermediaries and bringing inventory closer to the end user. These stores can stock essential seeds, pesticides, and fertilizers, en-

abling same-day or within few hours delivery to farmers.

Such a model can dramatically reduce distribution costs while significantly improving service levels.

This collaborative infrastructure approach would also help optimize inventory management, minimize stockouts, and improve product availability during critical farming windows.

Unlocking the Power of QR Codes and Digital Traceability

Another major opportunity lies in better use of existing digital tools.

Today, most agricultural companies have already implemented QR codes on product packaging. However, their potential remains largely under-utilised.

QR codes can become the foundation for:

- **Track and trace systems** to monitor product movement across the supply chain
- **Inventory tracking** for real-time stock visibility
- **Product authentication** to combat counterfeit products
- **Loyalty programs** to engage and reward farmers directly
- **Farmer education**, offering instant access to usage guidance and safety instructions

These technologies can create transparency and trust while enabling companies to connect directly with end users.

By embracing quick commerce, digital traceability, and collaborative supply-chain innovation, we can ensure that every farmer—no matter how remote—has timely access to the tools needed for productivity, prosperity, and growth

Beyond Individual E-Commerce Platforms

While many companies have launched their own e-commerce platforms, their success has been limited because these efforts often operate in isolation.

Agriculture needs a more collaborative ecosystem rather than fragmented individual platforms. Shared digital marketplaces, interoperable logistics systems, and common fulfillment networks can create scale and improve adoption.

Government support can play a transformative role here. Incentives, subsidies, and policy support for digitized agricultural supply chains can accelerate infrastructure development and encourage industry collaboration.

India already runs several successful public and private agricultural programs. Integrating digital supply chain capabilities into these initiatives can amplify their impact and help modernize rural commerce.

A Farmer-Centric Future

The future agricultural supply chain must be built around the farmer—making products available when and where they are needed, with full transparency and trust.

India remains one of the world's largest agricultural economies, and this gives us a unique opportunity to create a global benchmark in digital agri-distribution.

The next phase of agricultural progress will not only be defined by better seeds and better chemistry, but by how intelligently and rapidly we connect those innovations to the farmer.

India's agricultural transformation will not only be defined by better seeds and chemistry, but also by how intelligently and rapidly we connect those innovations to the farmer.

By embracing quick commerce, digital traceability, and collaborative supply-chain innovation, we can ensure that every farmer—no matter how remote—has timely access to the tools needed for productivity, prosperity, and growth.

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UREA IS POLITICALLY CHEAP
BUT AGRONOMICALLY EXPENSIVE

Prime Minister Modi's forex conservation appeal has opened a vital national conversation — one that science, ecology, and national economics have been waiting to have

On May 10, 2026, Prime Minister Narendra Modi made an appeal to the nation that was, on the surface, a response to an immediate foreign exchange crisis. Among seven measures he requested, one carried implications far deeper than its framing suggested: a call for farmers to reduce chemical fertiliser use by up to 50% and transition toward natural farming. The immediate trigger was unambiguous — the disruption to Strait of Hormuz shipping following the Iran conflict had driven crude oil above $100 per barrel, pushed global LNG prices up by 54% within days in Asian markets, and depleted India's forex reserves from $728.5 billion to approximately $691 billion within weeks. Over 30% of global urea — produced from natural gas — is exported from Gulf countries through the Strait of Hormuz. When that chokepoint closes, India does not merely face an energy problem. It faces an agricultural input crisis, a fiscal shock, and a food security question simultaneously.

But the Prime Minister's appeal, rooted in an immediate crisis, illuminates a structural vulnerability that has been building for decades. The question worth examining carefully — as scientists, economists, and citizens — is not merely how India reduces fertiliser imports in a crisis. It is why India became so dependent on an imported input chain for its food security in the first place, and what the full cost of that dependence has been — costs that extend well beyond the foreign exchange ledger.

About the **AUTHOR**

Dr. Purushottam M Dewang, Co-inventor of three USFDA-accepted anti-cancer drug candidates; translational scientist and Founder MD & CSO, CropG1 Agro Research & Development Pvt. Ltd., Bangalore. He has 25+ years of scientific experience at the interface of medicinal/ agricultural chemistry and biological sciences

A Pharmacologist's Observation on Dose and Response

In drug development, one of the foundational principles is the dose-response relationship — the understanding that a molecule's therapeutic benefit exists within a specific concentration range. Below that range, the drug is subtherapeutic. Above it, the same molecule becomes toxic. The challenge of medicine is identifying and maintaining the therapeutic window.

Nitrogen applied to agricultural soil follows a remarkably similar dose-response curve. At appropriate doses, nitrogen is transformative — it drove the Green Revolution and fed a food-deficit nation. India's debt to urea is real and should not be minimised. But dose-response curves are not linear indefinitely. Beyond the optimal range, the same nitrogen that produces yield begins producing a constellation of biological and ecological harms — to soil, to plant physiology, to the pest ecology of the farm, and ultimately to the farmer's own economics.

Indian agriculture, sustained by a subsidy architecture that has made urea the cheapest input decision available, has been operating well beyond the therapeutic window for years. The declining fertiliser response ratio is the most direct empirical signal of this: India's partial factor productivity of nitrogen — kilograms of grain produced per kilogram of nutrient applied — has fallen from approximately 13 kg in the 1970s to approximately 3–4 kg today. We are applying more of a molecule and receiving less from it. In pharmacology, this is called tolerance. In agronomy, it reflects a combination of soil biological degradation, nutrient imbalance, and ecological disruption that compound over crop cycles.

Three Distortions, One System Failure

Understanding why Indian farmers have arrived at this point requires examining three compounding distortions that the current fertiliser architecture has created — none of which are the farmer's fault.

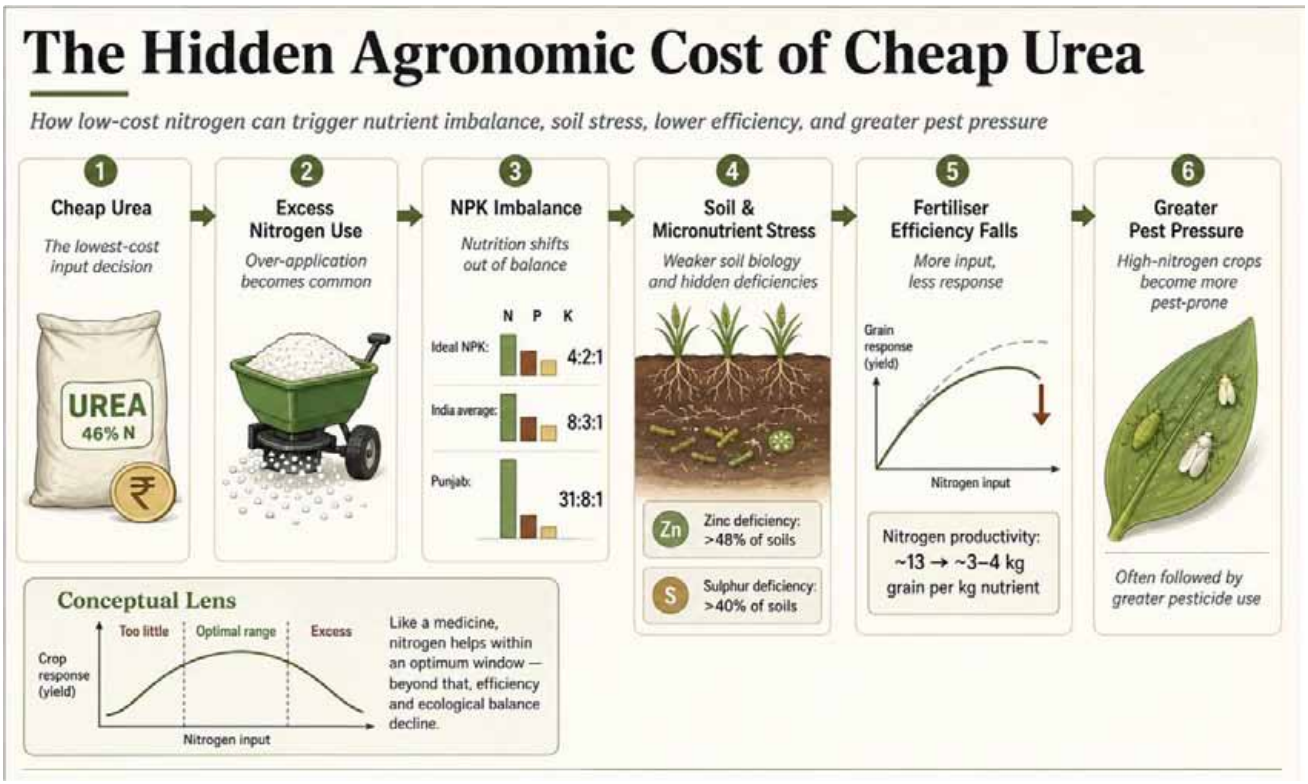
The fiscal distortion is the most visible. India spends approximately

India's market for biofertilisers, biopesticides, and biostimulants is growing but remains constrained by inconsistent product quality, inadequate cold-chain infrastructure, and price disadvantage relative to subsidised chemicals

Rs.1.75–2 lakh crore annually on fertiliser subsidies — a figure that fluctuates with global gas prices, shipping costs, and geopolitical events entirely beyond India's control. This is not merely a budgetary concern. The subsidy is structurally exposed to precisely the kind of geopolitical shock that the Strait of Hormuz disruption represents. When QatarEnergy declared force majeure on LNG production in March 2026, approximately 20% of global LNG was taken off the market. India's urea production economics, heavily dependent on imported LNG, were directly affected. A nation's nutritional strategy for its soil should not be hostage to events in the Persian Gulf — yet in the current architecture, it substantially is.

The nutrient distortion is less visible but agronomically more damaging. The agronomically recommended nitrogen-phosphorus-potassium (NPK) application ratio for balanced soil nutrition is approximately 4:2:1. India's national average has deteriorated to approximately 8:3:1. In Punjab — India's most intensively cultivated state and the cradle of the Green Revolution — the ratio has reached approximately 31:8:1. This is not a ratio. It is an agronomic imbalance of the first order. The consequence is measurable in micronutrient deficiency surveys conducted by ICAR and state agriculture departments: zinc deficiency affects over 48% of Indian soils, sulphur deficiency affects over 40%, and boron deficiency is increasingly documented.

These are not trivial deficiencies. Zinc is essential for over 300 enzymatic reactions in plant metabolism. Sulphur is critical for protein synthesis and chlorophyll formation. A crop grown in a zinc-deficient, sulphur-deficient, potassium-depleted soil is nutritionally compromised regardless of how much nitrogen it receives — in the same way that a patient receiving only glucose intravenously remains malnourished regardless of caloric intake. India is subsidising an input whose efficiency



has declined by nearly 70% over five decades. The subsidy has grown. The agronomic return has shrunk.

The behavioural distortion is perhaps the most important to understand — and the most frequently mischaracterised. Farmers apply urea heavily not because they are agronomically irrational, but because the price signal makes it their most rational available intervention. When one nutrient costs a fraction of the others, applying more of it is the lowest-risk visible decision — particularly in the absence of reliable soil diagnostics, functional extension services, and affordable alternatives. India currently has approximately one agricultural extension worker per 1,200 farmers against a recommended ratio of 1:400. In that advisory vacuum, the urea bag becomes a proxy for agronomic guidance. Blaming the farmer for this outcome is the equivalent of blaming a patient for self-medicating in the absence of a physician. The farmer is not the variable that needs correcting. The price signal is.

What Cheap Nitrogen Does to Soil

India's market for biofertilisers, biopesticides, and biostimulants is growing but remains constrained by inconsistent product quality, inadequate cold-chain infrastructure, and price disadvantage relative to subsidised chemicals

Biology

The agronomic consequences of sustained nitrogen excess extend into soil biology in ways that are only beginning to enter mainstream policy discussion. Healthy agricultural soil contains approximately one billion bacterial cells per gram, alongside complex fungal networks, nematodes, protozoa, and arthropods that collectively drive nutrient cycling, organic

matter decomposition, and plant root health. This is not background biology — it is the primary mechanism through which soil delivers nutrition to plants.

Arbuscular mycorrhizal fungi (AMF) deserve particular attention. These ancient symbiotic fungi colonise plant roots and extend their effective absorptive surface area by orders of magnitude, dramatically improving the plant's capacity to access phosphorus, zinc, and water from soil. The global scientific literature is unambiguous: AMF colonisation rates decline significantly under chronic high-nitrogen and high-phosphorus conditions. A 2019 meta-analysis published in Nature Communications examining 4,000 plant-fungal combinations found that nitrogen addition reduced AMF colonisation by an average of 15.6% globally, with more severe suppression under long-term application. Indian soils, subject to decades of nitrogen-heavy cultivation, have experienced measurable mycorrhizal suppression — meaning that the very biological system that could reduce fertiliser requirement is being progressively dismantled by the fertiliser regime itself. The therapeutic analogy holds with uncomfortable precision: the treatment is suppressing the immune system it depends upon.

Soil organic carbon (SOC) tells a similarly concerning story. Globally, productive agricultural soils require a minimum SOC of approximately 1.5–2%. Surveys across India's major agricultural states show large proportions of soils below 0.5% SOC — a level at which biological activity is severely compromised. China, which preceded India on the nitrogen-intensive agricultural trajectory by approximately 15–20 years, is now spending an estimated $15 billion annually on soil restoration programmes. The cost of prevention is a fraction of the cost of restoration — a principle as true in soil science as it is in preventive medicine.

The Nitrogen–Pest Connection: An Underappreciated Cascade

Perhaps the least-discussed consequence of nitrogen excess in Indian agricultural

India is subsidising an input whose efficiency has declined by nearly 70% over five decades. The subsidy has grown. The agronomic return has shrunk

policy circles is its ecological effect on pest populations — an effect with direct economic consequences for farmers and a forex dimension that connects back to the Prime Minister's appeal.

The mechanism is established in plant physiology and chemical ecology. High-nitrogen fertilisation produces crops with elevated concentrations of free amino acids and soluble nitrogenous compounds in their tissue. This biochemical signature is detectable by herbivorous insects through olfactory and gustatory receptors refined over millions of years of co-evolution. Aphids, whiteflies, thrips, and leafhoppers — the dominant sucking pest complex in Indian agriculture — show measurably higher reproduction rates, longer residency, and greater colony establishment on high-nitrogen plants. The seminal work of van Emden and Bashford in the 1970s, subsequently confirmed by dozens of studies across multiple cropping systems, established that foliar nitrogen concentration is among the strongest predictors of aphid population growth rate.

The ecological cascade does not stop at the pest. When farmers respond to elevated pest pressure with insecticide applications — as they rationally must — they disrupt the natural enemy complex: parasitic wasps, predatory beetles, syrphid flies, and spiders that provide biological suppression of pest populations. The disruption of natural enemies creates conditions for secondary pest outbreaks and for the development of insecticide resistance. India is among the world's largest consumers of pesticides, with the market estimated at approximately $5–6 billion annually and growing.

The farmer who over-applies urea may be unknowingly initiating a biological cascade that ends in an imported pesticide bill. Fertiliser policy and pesticide import dependence are connected through plant biochemistry and soil ecology — but that connection remains invisible in the absence of

integrated agronomic thinking.

What International Experience Teaches

Brazil's transformation of its soybean sector offers the most economically dramatic example. Faced with the cost of nitrogen fertilisation across its vast Cerrado agricultural region, Brazilian researchers developed large-scale inoculation programmes using Bradyrhizobium — nitrogen-fixing bacteria that colonise soybean roots and provide biological nitrogen at no import cost. Today, Brazilian soybean cultivation requires virtually no synthetic nitrogen fertiliser, saving the country an estimated $10–12 billion annually in fertiliser costs. The science is not novel — biological nitrogen fixation has been understood for over a century. The policy and extension infrastructure to deploy it at scale is the achievement.

The Netherlands offers a cautionary but instructive counterpoint. Decades of intensive livestock and crop production created a nitrogen deposition crisis that has required legally mandated nitrogen reductions of over 50% in sensitive areas. Dutch farmers resisted strenuously and politically — because the transition was imposed abruptly without adequate transition support. The lesson for India is not the Dutch regulatory model, which is unsuitable for Indian political and economic conditions. The lesson is the cost of delay: the Netherlands is now spending billions on a transition that earlier precision agriculture adoption could have made voluntary and economically beneficial.

What the Prime Minister's Appeal Actually Requires

The Prime Minister has identified the direction with clarity. Reducing chemical fertiliser use by 50% — the scale he has indicated — is agronomically achievable. The science supports it. The economics eventually favour it. The national security rationale is compelling. But the transition from appeal to outcome requires three infrastructural investments that Indian agriculture currently lacks at adequate scale.

The first is soil diagnostic intelligence — not the issuance of

A nation's nutritional strategy for its soil should not be hostage to events in the Persian Gulf — yet in the current architecture, it substantially is

Soil Health Cards, which has been accomplished at impressive scale, but the advisory infrastructure that translates a card's recommendations into a farmer's actual input decision. A card without an advisor is a diagnosis without a physician.

The second is quality-assured biological alternatives. India's market for biofertilisers, biopesticides, and biostimulants is growing but remains constrained by inconsistent product quality, inadequate cold-chain infrastructure, and price disadvantage relative to subsidised chemicals. The regulatory framework for biological inputs requires the same scientific rigour applied to conventional agrochemicals — not to restrict biologicals, but to build farmer trust through demonstrated efficacy.

The third is precision agriculture infrastructure accessible to small and marginal farmers — the 86% of Indian farmers who hold less than two hectares and for whom individually commissioned soil testing or satellite advisory is economically out of reach, but for whom village-cluster level diagnostic systems are entirely feasible with current technology.

The Prime Minister has opened a national conversation that science and economics have been pointing toward for years. The conversation is not about withdrawing support from farmers — it is about redesigning support, so it reaches the farmer's soil, the farmer's income, and India's strategic resilience with far greater efficiency.

India subsidised its way to food security in the twentieth century. The challenge of the twenty-first is to intelligence its way to food sovereignty. The cheapest bag in Indian agriculture has earned its place in history. Ensuring it does not also become the most expensive strategic liability of the coming decade — for the farmer, for the soil, and for the national exchequer — is a question of system design, scientific investment, and policy evolution. The Prime Minister has indicated the direction. The detailed map is the work that now follows.

Sowing the Seeds OF A DIGITAL REVOLUTION

India's agricultural sector, the backbone of its economy and the livelihood for more than 600 million people is at the cusp of a profound digital transformation. For decades, the narrative has been one of immense potential constrained by persistent challenges: fragmented landholdings, dwindling resources, and a heavy reliance on government subsidies. Now, a groundbreaking partnership between FarmX, an AI-native agricultural intelligence company, and Proximal Cloud, an enterprise-ready data sovereign AI compute provider, is set to rewrite this narrative, ushering in an era of unprecedented efficiency, profitability, and sustainability for Indian farming.

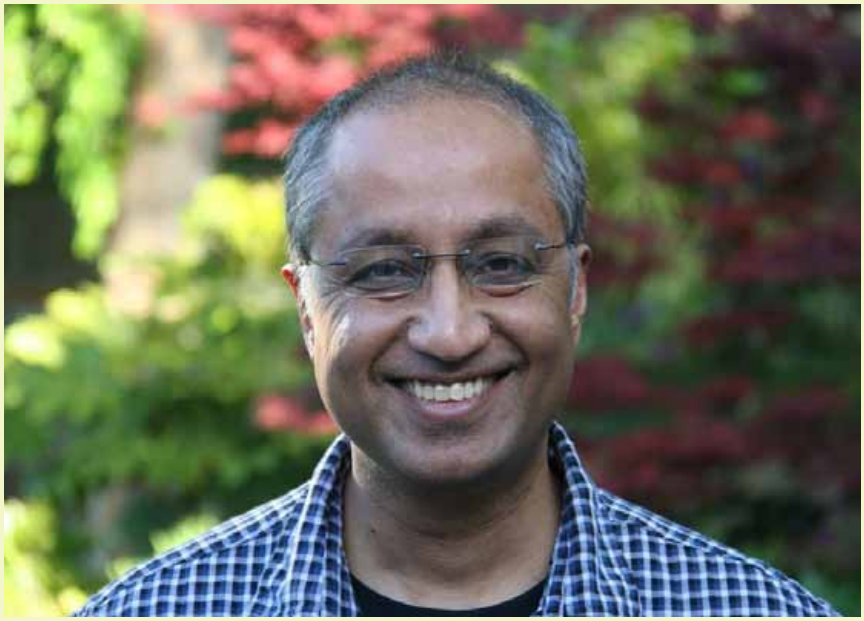
Announced at the prestigious India AI Impact Summit 2026, this strategic alliance is more than just a business collaboration; it's a comprehensive, technology-driven answer to some of the most deep-rooted issues plaguing Indian agriculture. The partnership aims to deploy production-grade artificial intelligence across vast, distributed farming operations, moving beyond isolated pilot projects to a system-wide, data-driven agricultural ecosystem.

The Challenge: A Field of Complexities

The Indian agricultural landscape, while vast and diverse, is fraught with complexities. Small and marginal farmers, who con-

About the **AUTHORS**

Mr Renu Raman is Founder and CEO, Proximal Cloud. Mr Premal Ashar is COO, FarmX



stitute the majority of the farming community, often struggle with limited access to technology and resources. Critical inputs like satellite imagery, sensor telemetry, and weather data remain siloed, hindering effective decision-making and automation. Furthermore, the increasing data intensity and geographical distribution of modern agriculture present significant challenges in terms of data sovereignty, security, and the high costs associated with cloud computing. These challenges point toward the emergence of an AI agronomist; a digital intelligence layer that complements farmers' traditional knowledge with real-time insights to improve yields, optimize water and fertilizer use, and drive better economic outcomes.

The Solution: A Two-Pronged Technological Offensive

The FarmX and Proximal Cloud partnership tackles these challenges with a powerful, two-pronged approach that combines on-the-ground automation with a robust, scalable data infrastructure.

FarmX: The Muscle and the Brains on the Ground

At the center of this transformation is FarmX's AI-driven farm intelligence platform, designed to bring automation and real-time decision support directly to agricultural operations. These are not merely sensors and machines; they are intelligent agents of agricultural transformation. With local manufacturing in works under the "Make in India" initiative, these devices are powered by a sophisticated AI/ML stack that analyzes a constant stream of data from various sources, including satellite imagery, IoT sensors, and on-the-ground conditions.

Proximal and FarmX are engaged with seamlessly integrating on-farm automation with a powerful data infrastructure to resolve long-standing challenges and unlock a future of sustainable prosperity

By automating critical farming operations, FarmX directly addresses the issue of labor scarcity while significantly improving efficiency. The result is a proven increase in farmer income, with projections showing a remarkable 40-50% rise over the next decade, translating to an additional $200-$500 per acre.

Proximal Cloud: The Unseen Engine of the Revolution

Powering FarmX's intelligent farming is Proximal Cloud's enterprise-grade AI data infrastructure. Proximal Cloud provides the crucial backbone that enables the collection, processing, and analysis of massive datasets. Their unique proposition lies in addressing the core concerns of complexity, sovereignty, and cost that have long hindered the adoption of AI in agriculture.

With its innovative "Crania" AI ready App Engine, Proximal Cloud brings compute closer to the data, rather than the other way around. This approach, combined with a network of high-capacity data centers across India, ensures data sovereignty and compliance with national security and regulatory requirements. The platform's ability to deliver a 50% lower Total Cost of Ownership (TCO) compared to alternative solutions makes advanced AI accessible and economically viable for the agricultural sector.

The Partnership: A Symbiotic Force for Change

The synergy between FarmX and Proximal Cloud is the true catalyst for this transformation. Proximal Cloud's scalable compute, storage, and networking capabilities provide the foundation for FarmX's platform, which encompasses machine learning, satellite analytics, IoT telemetry, and automation frameworks. This integrated architecture supports a continuous cycle of data ingestion, model execution, and decision orchestration, enabling a level of operational control and yield predictability

previously unattainable.

Mr. Renu Raman, CEO and Founder of Proximal Cloud, stated, "This partnership demonstrates how industrial scale cloud infrastructure can support real-world agri-AI systems at scale. Together with FarmX, the focus is on enabling resilient, production-ready platforms that improve decision-making and operational outcomes across complex agricultural ecosystems and realize the true vision of having every farmer with an AI agronomist as an assistant."

Mr Premal Ashar, COO of FarmX, echoed this sentiment, emphasizing that "Our partnership with Proximal Cloud helps create the digital foundation needed to bring AI-driven agriculture to scale across India. By combining advanced data infrastructure with FarmX's AI and automation platforms, we can deliver real-time intelligence directly to the field; helping farmers and agricultural enterprises make better decisions, improve productivity, and use critical resources like water and fertilizer more efficiently. This collaboration is an important step toward bringing Silicon Valley-style innovation to Indian agriculture and making AI agronomy accessible at national scale."

The Impact: Reimagining India's Agricultural Future

The implications of this partnership extend far beyond the farm gate, promising a ripple effect that will be felt across the nation.

For the Farmer: The most immediate and profound impact will be on the livelihoods of farmers. By optimizing the use of critical resources like land, water, and power, and by providing data-driven insights for better decision-making, the FarmX-Proximal Cloud solution empowers farmers to increase their yields and profitability, fostering a new generation of tech-savvy agricultural entrepreneurs.

For the Nation: On a national scale, the efficiency gains from this technological overhaul are projected to reduce the government's subsidy burden by an astounding Rs 5-6 trillion over the next ten years. Furthermore, the establishment of a national public data infrastructure for agriculture will enhance food security and position India as a global leader in agritech. This ambitious initiative, coupled with the local manufacturing of autonomous tractors, is a powerful testament to the success of the "Make in India" program and a significant step towards a self-reliant agricultural future.

The establishment of a national public data infrastructure for agriculture will enhance food security and position India as a global leader in agritech

Proximal Cloud

Founded in 2024, Proximal Cloud is an enterprise-grade cloud infrastructure provider that enables organizations to deploy, scale, and manage AI and data-intensive applications with reliability, security, and high performance. Headquartered in New Delhi, India, the platform supports advanced analytics, machine learning, and autonomous systems, providing the compute, storage, and networking capabilities required for large-scale, distributed operations. Proximal Cloud helps enterprises accelerate digital transformation by delivering robust, scalable, and interoperable cloud solutions that power intelligent decision-making, optimize operational efficiency, and drive innovation across industries including agriculture, energy, and manufacturing.

About FarmX

FarmX is a leader in AI-native agricultural intelligence, offering a fully integrated platform that combines machine learning, satellite analytics, IoT telemetry, automation frameworks, and autonomous electric tractors. Its solutions help large-scale farms optimize operations, improve yield predictability, and make sustainable, data-driven decisions across distributed agricultural operations.

A Harvest of Innovation

The partnership between FarmX and Proximal Cloud is more than just a technological advancement; it is a paradigm shift for Indian agriculture. By seamlessly integrating on-farm automation with a powerful data infrastructure, they are not just solving long-standing challenges but are also unlocking a future of sustainable prosperity. As India continues its journey towards becoming a global economic powerhouse, this collaboration will undoubtedly play a pivotal role in ensuring that the nation's agricultural heartland remains vibrant, productive, and ready for the challenges of the 21st century.

AGRIZY LAUNCHES GENAI STUDIO FOR NEXT-GEN FOOD & WELLNESS INNOVATION

Agrizy, India's leading techled Contract Research, Development and Manufacturing Organisation (CRDMO) for global Food & Beverages and Wellness brands, today introduced its proprietary GenAI-powered formulation platform that powers internal product development workflows, the first of its kind in India. The platform can turn product concepts into manufacturingready formulations in minutes, compressing typical New Product Development (NPD) cycles with respect to timelines and cost by up to 40%.

Unlike generic AI tools, Agrizy's platform offers a comprehensive formulation playground that goes far beyond simple recipe generation. The solution provides ranked formulation options along with ingredient quantities, costing insights, nutritional and allergen analysis, compliance validation, and export-ready lab documentation, enabling NPD teams to significantly accelerate product development workflows.

- Agrizy bring 5–10x more products to market compared to traditional CRDMO players.
- GenAI to reduce iteration cycles, eliminates fragmented development workflows, and embeds regulatory compliance from day one in Agrizy
- Agrizy is targeting India's food and beverage market is estimated to exceed USD 850 billion, driven by rising demand for packaged, functional, and value-added products across categories. At the same time, the global wellness market spanning nutraceuticals, beauty, cosmetics, and personal care exceeds USD 5 trillion

Teams can define key product parameters such as category, packaging options, target cost, shelf life, formulation preferences, marketing claims, ingredient restrictions, and sensory or performance profiles and receive actionable formulation outputs within minutes.

The platform also includes an integrated AI copilot that enables teams to formulate or re-formulate products using natural language instructions. This AI-assisted workflow allows continuous optimization across ingredients, claims, compliance requirements, nutrition profiles, and end-use performance parameters, making the product development process faster, smarter, and significantly more iterative.

By integrating GenAI formulation studio into its operations, Agrizy has been able to bring 5-10x more products to market compared to traditional CRDMO players.

Pivotal Moment

This launch comes at a pivotal time. India's food and beverage market is estimated to exceed USD 850 billion, driven by rising demand for packaged, functional, and value-added products across categories. At the same time, the global wellness market spanning nutraceuticals,

Mr. Arun Markish is the Co-Founder and CTO of Agrizy

beauty, cosmetics, and personal care exceeds USD 5 trillion, reflecting accelerating consumer demand for preventive health, personalization, and ingredient-led innovation, underscoring the immense potential for faster, more efficient product innovation across the Food & Beverages and Wellness space.

Innovation in formulation science has traditionally depended on fragmented workflows, repeated manual experimentation, and disconnected validation cycles. We engineered the system to solve core inefficiencies and unify ingredient ontology, formulation logic, regulatory constraints, and lab feedback into a single intelligence layer that continuously improves with every iteration. This allows R&D and product teams to simulate, refine, and validate formulations with greater accuracy before moving into physical trials, significantly improving development efficiency, scalability, and speed to market.

Every approved formulation feeds directly into Agrizy's inhouse labs, where realworld bench trial data including yield, stability, sensory results, and quality parameters continuously sharpen the AI's recommendations. This ensures the system improves with every batch, not just every model update.

Mr. Anandmayi Priyadarshini, Director - Personal care of Agrizy, added, "Formulations Studio has significantly accelerated the way we approach new product development for the global brands we work with. Our Gen AI-driven platform acts as a copilot for our in-house R&D team, helping reduce formulation timelines by minimizing lab iterations from the ideation stage, improving accuracy, and enabling faster delivery of commercially viable solutions. The platform has enabled us to develop and launch nearly 5x more products compared to traditional CDMO."

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Three Vital Layers

The platform's differentiation is built on three layers that are difficult to replicate: an India-specific ingredient ontology tagged with FSSAI, FDA, and EFSA regulatory status; formulation memory that learns from failed combinations, not just successful ones; and constraint guardrails for instance, automatically excluding lanolin-derived Vitamin D3 for vegan formulations or flagging non-compliant sweetener combinations.

Founded in 2021 by Mr Vicky Dodani and Mr Saket Chirania, Agrizy is a Series A, funded tech-led CRDMO for global Food & Beverages (F&B) and Wellness brands. The company acts as an end-to-end backend catalyst, enabling the complete product lifecycle, from concept ideation and R&D led formulation development to ingredient sourcing, manufacturing and global fulfillment. Agrizy helps brands accelerate new product development, reduce cost-to-market, and scale existing product lines with speed, consistency, and compliance. By integrating GenAI capabilities, in-house R&D, tech-enabled quality systems, and processing infrastructure, Agrizy is building a scalable, intelligence-led backbone for the global F&B and Wellness industry. Today, Agrizy partners with 200+ global F&B and wellness brands across 20+ countries and is backed by leading investors including Accion, Ankur Capital, Capria, Omnivore, and Thai Wah Ventures.

QUANTUM NEW NORM IN AYURVEDA

PROCESSING SCIENCE IS REWRITING INDIA'S BOTANICAL STORY

India has long been Ayurveda's origin. Today, it is poised to become its most advanced future — not by discovering new herbs, but by fundamentally reimagining how the ones we have always known are processed, activated and delivered to the world.

For centuries, the global wellness industry has cycled through the same cast of hero ingredients. Curcumin from turmeric. Withanolides from ashwagandha. Bacosides from bacopa. Amla, tulsi, neem — each has gone through multiple waves of extraction claims, bioavailability narratives and branding exercises. The conversation has remained stuck on one question: which herb comes next?

The more disruptive question — and the one the industry is beginning to wake up to — is this: Can the same herb be made to work faster, cleaner and more efficiently, without chemical carriers, synthetic enhancers or invasive processing? That is precisely what a new processing paradigm called Quantum Ayurveda is designed to answer.

A Market Ready for Disruption

The numbers alone signal the scale of opportunity. The global herbal nutraceuticals market was valued at USD 77.6 billion in 2025 and is forecast to reach USD 140.28 billion by 2034, growing at a CAGR of 6.8%, according to Precedence Research. India's own nutraceutical market — valued at USD 6.11 billion in 2024 — is projected to reach USD 11.55 billion by 2030 at a CAGR of 11.39% (Research and Markets, 2025).

About the **AUTHOR**

Mr Shafiulla Hirehal Nuruddin is the Founder and Managing Director of Greenspace Herbs, a company that bridges ancient Ayurveda with modern science. Instead of relying on heavy chemical solvents or synthetic enhancers to boost bioavailability, the company uses quantum chemistry, biology, and clean, sub-molecular frequency processing to change how classical Ayurvedic ingredients are activated and delivered

India's AYUSH and herbal exports have also shown consistent upward momentum, growing 6.11 per cent from USD 649.2 million in 2023-24 to USD 688.89 million in 2024-25, according to the Ministry of Commerce and Industry. Meanwhile, the broader Indian AYUSH market is projected to grow from USD 43.3 billion in 2024 to USD 200 billion by 2030 — an eightfold expansion over the decade (Ministry of AYUSH, 2025).

These are not numbers driven by novelty alone. They reflect a structural convergence of three powerful demand forces: the clean-label movement, the shift to plant-based health solutions, and the global preference for science-backed botanicals. The challenge has been finding ingredients that sit credibly at the intersection of all three.

The Processing Problem No One Was Solving

What has quietly held back Ayurveda's global commercial breakthrough is not the quality of its ingredients, but the limitations of how they are processed. Conventional nutraceutical extraction — which relies heavily on chemical solvents, synthetic carriers and formulation interventions — has allowed the industry to improve bioavailability, but often at the cost of the ingredient's natural profile.

A 2023 DNA barcoding study published in the Journal of Food Composition and Analysis found that over 25% of herbal supplements tested globally contained undeclared or substituted ingredients — a credibility crisis that points directly to the need for cleaner, more traceable processing methods. Meanwhile, regulatory bodies including the US Pharmacopeia and the European Medicines Agency are increasingly pressing for standardized assays, transparent labeling and GMP compliance.

The challenge of bioavailability itself is well-documented. Curcumin — arguably the most studied nutraceutical ingredient in the world — has notoriously poor absorption when consumed in conventional form. Most extraction and enhancement methods have historically involved piperine, phospholipid complexes or nanoparticle encapsulation — all effective but carrying their own formulation baggage. The industry has long searched for a cleaner answer.

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Quantum Ayurveda: A Processing Architecture, not a Product

It is into this gap that Greenspace Herbs has introduced Quantum Ayurveda — a proprietary processing platform built on the principle of frequency-led clean processing. The approach uses controlled frequencies and quantum chemistry to influence botanical ingredients at a molecular level, without solvents, synthetic enhancers or heavy chemical intervention.

The critical distinction is architectural. This is not a new herb, a new extract or a new delivery format. It is a processing framework — one that activates the existing potential of classical Ayurvedic botanicals while preserving their natural identity and eliminating the chemical footprint that has long shadowed commercial nutraceuticals.

Where conventional processing relies on chemical carriers to ferry active compounds into the bloodstream, frequency-led processing proposes a different mechanism: resonance and molecular activation that keeps the ingredient closer to its natural state while improving how it behaves in the body.

Global Validation — and the Scalability Imperative

The global market has begun to respond. At Vitafoods Barcelona — one of the world's most significant nutraceutical trade platforms — Greenspace Herbs recorded over 280 formal global leads for the Quantum Ayurveda platform. Interest from European and ASEAN buyers has been particularly strong, two regions where regulatory rigor around clean-label certification is among

the highest in the world.

But early-stage validation now gives way to the more demanding question of scalability. Quantum Ayurveda is precision small-batch technology. Control, repeatability and energetic integrity are non-negotiable parameters. Current capacities are equipped to serve early-stage demand from the USA and India. Whether this technology can scale to continental commercial supply — while retaining the consistency that defines its edge — is the defining challenge of the next phase.

It is a challenge the broader industry must watch closely. A DNA barcoding crisis, rising regulatory pressure and the clean-label imperative have collectively created the conditions for a processing revolution. The question is which technologies can deliver at scale without compromising on the principles that created their market differentiation in the first place.

India's Larger Opportunity: From Custodian to Creator

There is a story beyond the product here that agriculture and agri-processing India should pay close attention to. Historically, India's role in the global botanical supply chain has been that of raw material provider — the source of ashwagandha, turmeric, tulsi, amla and dozens of other ingredients that global supplement brands then process, enhance and sell to premium markets.

Quantum Ayurveda is not a product innovation — it is a processing revolution. For centuries, India has given the world its most powerful botanicals. What we are now adding is the science of how those botanicals can be made to perform at their fullest potential, without compromising their natural integrity

Quantum Ayurveda introduces a different positioning: India as a creator of next-generation clean-processing technologies with global intellectual property value. The WHO Global Centre for Traditional Medicine, which the Government of India is hosting at Jamnagar, already signals India's ambitions to be not just a heritage custodian of traditional medicine but an active scientific contributor to its global future.

AYUSHEXCIL — the Ayush Export Promotion Council established by the Ministry of Ayush — has been actively building frameworks to strengthen quality assurance and international regulatory compliance. The recent launch of the Ayush Quality Mark programme during the 2nd WHO Summit on Traditional Medicine (December 2025) is one such step. These infrastructure moves matter. Because technologies like Quantum Ayurveda need the international credibility architecture around them to unlock their full export potential.

What Comes Next

Greenspace Herbs is bringing the Quantum Ayurveda platform to two of the year's most strategically important nutraceutical gatherings: the NutraSumflex C-Suite platforms in Tashkent (May 2026) and Mumbai (June 2026) — international forums where the industry's decision-makers will scrutinise not just what the technology claims, but whether it can deliver at commercial scale.

The category excitement has been created. Now comes category proof. And for India — a nation that is simultaneously the world's oldest Ayurvedic civilisation and one of its most ambitious nutraceutical exporters — the stakes of getting this right extend well beyond one company's balance sheet.

The next era of Ayurveda will not be defined only by which ingredient is chosen. It will be defined by how intelligently, cleanly and scalably that ingredient is processed. That is the bet Quantum Ayurveda is making. And it is a bet the global market appears increasingly willing to consider.

GENOME EDITING AND AI-BASED BREEDING

Transforming Seed Research

Future agriculture confronts a convergence of formidable challenges that threaten global food security. Climate change is accelerating, with rising temperatures, erratic monsoons, prolonged droughts, floods, and unseasonal heatwaves and rainfall, all of which severely impact rice productivity, the staple food for over half the world's population. Traditional seed breeding has long driven yield gains. Still, it struggles to keep pace with the need to combine higher productivity, enhanced nutritional quality, and resilience to biotic and abiotic stresses. Innovations in seed research, particularly genome editing and AI-based breeding, can transform crop improvement, delivering varieties that combine higher yield, disease resistance, herbicide tolerance, and fortified nutrition.

About the **AUTHORS**

Mr Arvind Kumar has done significant work on drought tolerant rice and is the Global Research Director, Research and Development, Prasad Seeds Private Limited, Hyderabad. Dr. Manish Solanki is a Scientist working on Genome Editing and has played a vital role in the development of India's first Genome Edited Rice variety Kamala (DRR Dhan 100)

Genome editing enables precise, targeted modifications to a plant's own DNA, bypassing the lengthy timelines of conventional crossing (often 8–12 years). Unlike older transgenic methods, modern editing tools such as base editors and prime editors introduce small, heritable changes without foreign DNA, thereby easing regulatory hurdles in India. AI-based breeding complements this by analyzing vast genomic, phenotypic, and environmental datasets to predict optimal traits and accelerate selection.

In rice, genome editing has delivered breakthroughs in disease resistance, a major yield limiter. Multiplex editing of susceptibility (S) genes such as OsERF922, Pi21, and OsSWEET14 has conferred stacked resistance against multiple pathogens (bacterial blight and blast) by upregulating salicylic and jasmonic acid pathways without compromising agronomic traits. Higher-yield traits are similarly enhanced. The well-known genes controlling plant architecture, such as D3 and TB1 for tillering and culm length, produce compact, high-tillering plants with improved light capture and grain filling. Yield-related QTLs such as GS3 (grain size), Gn1a (panicle number), and GW3 (grain width) have been targeted, resulting in 15-40% gains in grain weight or number per panicle. Knockout of *OsVIT1* and *OsVIT2* (vacuolar iron transporters) redirects Fe from vacuoles to endosperm, increasing polished-grain Fe up to 6-fold. CRISPR knockouts in elite varieties have produced lines with ultra-low GI (<45) and doubled protein (up to 16%), without yield loss.

A strategic response to water labour shortages in agriculture is the accelerated transition from transplanted rice to direct-seeded rice (DSR) systems

Importance of Direct Seeded Rice

A strategic response to water labour shortages in agriculture is the accelerated transition from transplanted rice to direct-seeded rice (DSR) systems. DSR eliminates the need for puddling and transplanting, delivering 30-50% water savings, 20-60% labour reduction, lower methane emissions, earlier maturity, and easier mechanization. However, successful DSR adoption hinges on overcoming higher weed pressure and abiotic stresses. A powerful application of genome editing in seed research is the development of herbicide-tolerant crops. Using CRISPR/Cas9, base editors, and prime editing, scientists can precisely modify key genes such as *OsALS* (acetolactate synthase) in rice. Similar edits to *OsEPSPS* have produced glyphosate-tolerant rice.

While genome editing provides the scalpel, AI-based breeding supplies the blueprint. Artificial intelligence integrates multi-omics data (genomics, transcriptomics, phenomics, enviromics) to bridge the genotype-phenotype gap. Machine learning models, such as random forests, convolutional neural networks, and deep learning, predict trait performance from genomic markers, accelerating genomic selection (GS) by 30-50% compared to traditional methods. Phenomics platforms can generate high-dimensional datasets on growth, stress response, and yield components. AI then mines genebanks for rare al-

leles, designs optimal crosses, and forecasts outcomes. Breeding programs can use AI for intelligent germplasm design: breeders set goals (+20% yield, low-GI, high-Zn), and algorithms output actionable strategies.

India's private seed sector, already controlling more than 70% of the formal seed market, stands at a historic inflexion point. With the May 2025 approval of the world's first genome-edited rice varieties (DRR Dhan 100/*KAMALA* and Pusa DST Rice 1) by ICAR, and the 2022 regulatory exemption of SDN-1 and SDN-2 edits from stringent GMO oversight, edited crops are now treated almost like conventionally bred varieties. This, combined with the forthcoming Seeds Bill 2025, which emphasises digital traceability, farmer rights under PPVFR, and streamlined quality standards, creates a clear runway for private companies to accelerate innovations.

To fully harness the innovations in seed research, private companies must move beyond traditional hybrid development. Private companies should Forge Deep Public-Private Partnerships (PPPs) with public institutions (ICAR-IIRR, IARI, DBT) as the core strategy, and build in-house Genome Editing + AI Platforms with an India-centric focus by investing in or partnering with CRISPR-Cas9/prime/base editing/AI-based research.

Private companies should actively target DSR-ready stacks such as herbicide tolerance (*OsALS*/*OsEPSPS* edits for imazethapyr/glyphosate) + rapid seedling vigour + drought/salinity tolerance + weed competitiveness, as well as stacking nutritional traits: higher Zn/Fe (via *OsVIT*, *OsNAS2*, ferritin edits), low-GI (*SBEIIb* knockouts for resistant starch).

Need to Check Impediments to DSR

Private companies should prioritise DSR as the market-entry vehicle and lead the shift to DSR by commercialising herbicide-tolerant, high-vigour edited varieties that solve the DSR barrier weeds. Bundle seeds with mechanised DSR equipment, precision herbicide application advisory

Companies that act decisively can capture 20-30% market share gains in rice seed within 5 years. Early movers will benefit from Rs 500 crore government genome-editing funding, BioE3 policy incentives, and "Seeds without Borders" scaling mechanisms

(via AI apps), and farmer training. Marketing packages that deliver 15-20% higher effective yield under direct seeding while cutting cultivation costs and methane emissions, and place companies as "climate-smart solution providers" rather than mere seed sellers.

Private companies should take active steps to launch premium "Nutri-Resilient DSR Rice" hybrids that combine higher yields, disease resistance, Zn/Fe fortification, and low-GI. Target nutrition-sensitive states (Bihar, Odisha, UP, Jharkhand) valuing climate-smart grains. Certify varieties under climate-resilient, low-emission, and biofortified labels to access government subsidies, carbon credits, and corporate procurement.

Companies that act decisively can capture 20-30% market share gains in rice seed within 5 years. Early movers will benefit from Rs 500 crore government genome-editing funding, BioE3 policy incentives, and "Seeds without Borders" scaling mechanisms. The payoff: higher farmer incomes, measurable reductions in water/labour use, improved national nutrition security, and India emerging as the global hub for precision-bred rice.

Private-sector seed research in India should position itself as a bridge between public innovation and farmer fields, agile, collaborative, and farmer-centric. The regulatory window is open; the technology is proven; the market is ready. Those who invest now in PPPs, indigenous capability, and DSR solutions will lead the next Green Revolution.

Acting on this strategic imperative, Prasad Seeds Pvt. Ltd. (PSPL) has taken decisive steps to bridge the gap between advanced technology and the farmers' field. PSPL has established an in-house Genome Editing Platform, established strategic collaboration with different international organizations and is actively building a robust public-private consortium dedicated to comprehensive rice improvement. While our immediate focus is firmly on revolutionizing rice, PSPL is simultaneously laying the operational groundwork to extend these methodologies to other vital crops in the near future.

RAJASTHAN PARTNERS WITH WADHWANI AI TO BOOST SMART FARMING

The partnership will focus on deploying AI-powered solutions across agriculture advisory, pest and disease surveillance, farm-level data digitization, and quality assessment to strengthen agriculture delivery systems and improve farmer outcomes across Rajasthan

The Government of Rajasthan and Wadhwani AI (LEHS AI Unit) signed a Memorandum of Understanding (MoU) to collaborate on the deployment and integration of artificial intelligence (AI)-driven solutions across the state's agriculture ecosystem. The partnership aims to support Rajasthan's ongoing efforts towards improving farmer access to timely advisories, strengthening field-level intelligence systems, enhancing agricultural data visibility, and enabling more responsive agriculture delivery mechanisms through AI solutions designed for Indian conditions.

About the **AUTHOR**

Dr. Neeraj Agrawal is Chief Program Officer, Wadhwani AI

MOU Shall Strengthen AI-Enabled Agriculture Systems Across The State

Under the partnership, Wadhwani AI will serve as a technical partner to the state, supporting the deployment, integration, and implementation of AI-driven tools aligned with Rajasthan's agricultural priorities and digital transformation initiatives. Across India, Wadhwani AI has been building and deploying AI-powered agriculture solutions that strengthen farm resilience, improve productivity, and enhance the efficiency of agricultural systems at scale.

Through a portfolio of solutions spanning crop advisory, pest and disease surveillance, farm-level digitization, agricultural intelligence, grievance redressal, and quality assessment, Wadhwani AI has reached more than 1 million farmers across 10 states in India through collaborations with government departments, research institutions, and ecosystem partners. Building on these nationwide deployments and learnings, Rajasthan presents a strong opportunity to deepen and scale AI adoption in agriculture.

As one of India's largest and most diverse agricultural states, Rajasthan offers significant potential for scalable AI deployment across crop advisory, pest and disease surveillance, farm-level digitization, agricultural intelligence, and quality assessment. The state also has a strong animal husbandry sector, complemented by substantial opportunities in agroforestry, enabling integrated and climate-resilient rural development interventions.

The solutions to be deployed in the state include the following.

AgriVaani: A multilingual, multimodal conversational AI app designed to provide tailored agricultural advisories to farmers and extension workers through voice and text interactions in local languages. Powered by an agriculture domain-specific language model, the solution enables users to ask agriculture-related questions and receive actionable responses, helping bridge the gap between existing agricultural knowledge and access, particularly in underserved regions.

CropAce: A computer vision-based AI solution designed to identify crop pests and diseases from field images and provide recommendations for timely intervention. CropAce can support early detection of threats, enable safer pesticide use to reduce crop losses, and improve extension service delivery through AI-assisted diagnostics and outbreak visibility.

Soybean Grain Analyzer (SGA): An AI-powered smartphone app that uses computer-vision-based evaluation to objectively assess soybean grain quality. The solution is designed to support farmers, Farmer Producer Organizations (FPOs), and buyers through standardized quality assessment, helping improve transparency during procurement and pricing discussions.

News Monitoring in Agriculture (NMA): An AI-powered agriculture news monitoring solution designed to help agriculture departments track and respond to critical agriculture-related developments in near real time across English and regional languages. The platform uses AI and machine learning to identify, categorize, and summarize relevant news signals, including pest outbreaks, crop diseases, weather disruptions, and agricultural market-related developments, enabling faster alerts, improved field-level visibility, and more responsive decision-making across the agriculture ecosystem.

"Rajasthan has been actively working towards strengthening agricultural systems, improving farmer access to timely information, and promoting the adoption of modern technologies across the agriculture ecosystem. Artificial Intelligence presents a significant opportunity to further enhance these efforts by enabling more informed decision-making, improving extension services, and supporting farmers with accessible, data-driven tools. Through this partnership with Wadhwani AI, we look forward to exploring and implementing AI-powered solutions that can strengthen agriculture delivery systems and improve outcomes for farmers across the state," said Mr. Naresh Kumar Goyal, IAS, Commissioner Agriculture, Government of Rajasthan.

Through this partnership with Wadhwani AI, we look forward to exploring and implementing AI-powered solutions that can strengthen agriculture delivery systems and improve outcomes for farmers across the state

- Mr. Naresh Kumar Goyal, IAS, Commissioner Agriculture, Rajasthan

Speaking on the collaboration, Dr. Neeraj Agrawal, Chief Program Officer, Wadhwani AI, said, "We are grateful to the Department of Agriculture, Government of Rajasthan for the opportunity to collaborate on this important initiative. The future of agricultural resilience and productivity will increasingly depend on how effectively technology can strengthen frontline systems and improve access to actionable information for farmers at scale. The solutions being explored under this collaboration span multiple aspects of the agricultural value chain, from localized advisory and pest intelligence to digitized farm records and technology-enabled quality assessment. We look forward to supporting scalable, responsible AI deployments that can strengthen agriculture delivery systems and improve farmer outcomes across the state."

Beyond the initial deployment areas, the partnership will also explore future AI-enabled use cases across Rajasthan's agriculture ecosystem, including agricultural intelligence, predictive systems, and decision-support capabilities that can strengthen agriculture delivery at scale. The collaboration builds on Wadhwani AI's work with governments and ecosystem partners across India, where its technology solutions currently reach over 190 million people across agriculture, health, and education.

About Wadhwani AI

Wadhwani AI is a cross-domain, Indian not-for-profit institute, developing and deploying AI solutions with a mission to create impact at scale and improve lives and livelihoods. The organization works with governments and cross-sectoral partners to build trusted and responsible last-mile solutions that strengthen India's core development indicators across agriculture, health, and education.

Beyond Ethanol

WHY INDIA MUST URGENTLY EMBRACE BIODIESEL

India's continuing dependence on imported crude oil has once again become a matter of grave national concern in the backdrop of the ongoing Iran conflict and rising geopolitical instability in West Asia. Every escalation in the region sends shockwaves across global energy markets, pushing up crude oil prices and placing immense pressure on oil-importing nations like India. For a country that imports nearly 85 percent of its crude oil requirements, such developments directly impact inflation, fiscal stability, foreign exchange reserves and overall economic growth.

At a time when India is facing both economic and energy security challenges, the country urgently needs to accelerate the development of indigenous alternatives to fossil fuels. Among all available options, biodiesel stands out as one of the most practical, scalable and strategically important solutions for India's future.

Biodiesel vs Ethanol: The Policy Imbalance

Despite years of discussion around renewable fuels, India's policy focus has remained disproportionately tilted towards ethanol blending, while biodiesel — which has immense potential in a diesel-driven economy like India — has remained largely neglected. This policy imbalance needs immediate correction. One of the biggest ironies of India's biofuel policy is that while the government has aggressively promoted ethanol blending, biodiesel has remained largely neglected. India's ethanol blending programme has undoubtedly achieved scale, with blending levels approaching 20 percent. However, ethanol is not without environmental and economic concerns.

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Mr Vishal Rawat is an Agricultural Economist by qualification. He is currently working as Director General, Biodiesel Manufacturers Association of India, New Delhi. Besides involved in plantation activities and field surveys through my company Agri Ennovations OPC Private Limited

Ethanol's Hidden Costs

Large-scale ethanol production in India increasingly relies on:

- Sugarcane
- Food grains such as maize and rice

This creates several concerns:

- High water consumption
- Pressure on food security
- Intensive fertilizer usage
- Significant land requirement
- Higher lifecycle emissions compared to biodiesel in many cases
- Sugarcane cultivation itself is highly water-intensive and contributes substantially to groundwater depletion in several states.
- Further, grain-based ethanol raises ethical and economic questions in a country where food inflation and agricultural distress remain persistent concerns.

Biodiesel Has a Lower Carbon Footprint

Biodiesel produced from:

- Used cooking oil
- Non-edible oilseeds
- Waste fats
- Tree-borne oilseeds

can deliver substantially lower lifecycle greenhouse gas emissions compared to fossil diesel and, in many cases, lower emissions than crop-based ethanol pathways.

Biodiesel also offers additional ecological advantages:

- Better biodegradability
- Lower sulphur emissions
- Reduced particulate matter emissions
- Improved lubricity in engines
- Most importantly, biodiesel can

be produced from wastelands and waste resources without directly competing with food crops.

India is fundamentally a diesel economy. Diesel powers the country's freight movement, agricultural machinery, mining operations, railways, construction sector, generators and public transportation systems. Annual diesel consumption in India today exceeds 90 billion litres. Even a modest blending of biodiesel with conventional diesel can therefore generate enormous economic and strategic benefits.

A 20 percent biodiesel blending programme is technically feasible and can substantially reduce India's dependence on imported petroleum diesel without requiring major changes in existing diesel engines or fuel distribution infrastructure. Unlike electric mobility, which requires massive investments in charging infrastructure and grid modernization, biodiesel can be integrated immediately within the existing fuel ecosystem.

The economic implications of such a transition are enormous. Assuming current diesel consumption levels and prevailing import-linked diesel prices, India can potentially save massive amounts of foreign exchange through biodiesel blending.

These estimates are conservative and actual savings could be significantly higher during periods of elevated crude

Biodiesel Blending Level	Estimated Annual Forex Savings
1% blending	Rs.6,750 crore
2% blending	Rs.13,500 crore
5% blending	Rs.33,750 crore
10% blending	Rs.67,500 crore
20% blending	Rs.1.35 lakh crore

The present geopolitical situation should now serve as a wake-up call for India. Energy security can no longer remain dependent solely on imported crude oil and global supply chains vulnerable to war and instability. India requires a diversified and resilient renewable fuel strategy in which biodiesel must play a central role

oil prices such as those witnessed during geopolitical crises. Yet, despite such enormous strategic advantages, India's biodiesel sector continues to remain underdeveloped. Current biodiesel blending levels in the country remain below one percent, far below even the modest national target of 5 percent blending. This is in sharp contrast to ethanol blending, which has rapidly expanded to nearly 20 percent due to strong policy support, assured procurement and financial incentives.

The success of the ethanol programme demonstrates that India has the institutional capacity to scale renewable fuels when there is clear political will and policy continuity. Unfortunately, biodiesel has never received similar support. This is particularly surprising because biodiesel, in many respects, offers superior environmental and sustainability advantages over ethanol.

Large-scale ethanol production in India increasingly depends upon sugarcane and food grains such as maize and rice. Sugarcane is among the most water-intensive crops cultivated in the country and has contributed significantly to groundwater depletion in several regions. Grain-based ethanol also raises difficult questions regarding diversion of agricultural produce away from food systems in a country where food inflation and nutritional challenges continue to persist.

Biodiesel, on the other hand, can be produced from non-edible oilseeds, tree-borne oilseed species, used cooking oil, animal fats and industrial waste oils. Biodiesel production therefore does not necessarily compete directly with food crops. In addition, biodiesel derived from waste resources and non-edible feedstocks generally has a lower lifecycle carbon footprint compared to many crop-based ethanol pathways.

Environmental Advantages

Biodiesel also provides several environmental advantages including lower sulphur emissions, reduced particulate matter emissions, improved engine lubricity and better biodegradability. More importantly, it offers India the opportunity to convert waste into wealth through a circular economy model based on used cooking oil and industrial residues.

The current crisis in West Asia should compel policymakers to rethink India's energy priorities before the country once again finds itself exposed to another global oil shock. Biodiesel is no longer an option that India can afford to ignore

India had once envisioned becoming a global leader in biodiesel through large-scale plantation programmes involving Jatropha and other non-edible oilseed crops. However, the programme eventually failed due to lack of scientific planning, poor quality planting material, absence of assured procurement, weak institutional support and inconsistent policy implementation. As investor confidence collapsed, large portions of installed biodiesel production capacity became idle.

The present geopolitical situation should now serve as a wake-up call for India. Energy security can no longer remain dependent solely on imported crude oil and global supply chains vulnerable to war and instability. India requires a diversified and resilient renewable fuel strategy in which biodiesel must play a central role.

A serious national biodiesel mission can generate multiple long-term benefits. It can reduce crude oil imports, save valuable foreign exchange, generate rural employment, promote wasteland development, support agroforestry systems and contribute significantly towards India's climate commitments. Millions of hectares of degraded and underutilized land across India can potentially be brought under cultivation of suitable tree-borne oilseed species, creating new livelihood opportunities in rural and tribal regions.

What India now requires is a mission-mode approach towards biodiesel similar to the one adopted for ethanol. This includes establishment of a National Biodiesel Feedstock Mission, assured long-term procurement by oil marketing companies, fiscal incentives for biodiesel producers, scientific feedstock development programmes, strong used cooking oil collection systems and integration of biodiesel projects with carbon credit mechanisms.

India cannot achieve true energy security merely through electric mobility or ethanol blending. Diesel will continue to remain the backbone of India's economy for decades to come. In such a scenario, biodiesel represents not just an alternative fuel, but an instrument of national economic resilience and strategic sovereignty.

The current crisis in West Asia should compel policymakers to rethink India's energy priorities before the country once again finds itself exposed to another global oil shock. Biodiesel is no longer an option that India can afford to ignore.

WHOLE WHEAT

A NUTRITIONAL EPICENTER OF DIETARY FIBER FOR BETTER GUT HEALTH

Dietary fibre (DF) refers to the non-digestible parts of plant cells that resist digestion in the small intestine, offering various health benefits. It includes structural polysaccharides such as cellulose, hemicellulose, pectin, resistant starch, and lignin. DF is categorized by solubility, viscosity, and fermentability, which influence satiety, glycemic control, bowel health, and gut microbiota composition. Fermentable fibres produce short-chain fatty acids (SCFAs), which support gut health and reduce the risks of gastrointestinal disorders. Wheat, a widely consumed staple, is a rich source of both soluble and insoluble fibres, especially in its bran. Whole wheat retains all parts of the grain, providing significantly more fibre (~13%) compared to refined flour (~2.7%), which loses bran after milling. Incorporating whole wheat products like chapatti and whole-grain bread improves SCFA production, gut microbiome diversity, and metabolic health. Promoting whole-grain consumption is vital for enhancing fibre intake and supporting overall human health.

Crucial Role In Managing Many Chronic Health Diseases

Dietary fibre (DF) has gained great attention these days owing to its crucial role in managing many chronic health diseases. Increased fibre consumption has been shown to maintain blood sugar levels, improve digestive health, better body weight, and lower cholesterol and the risk of certain cancers. Recognizing its importance, the World Health Organization (WHO) recommends a daily intake of 25–30g of DF per adult. However, this exact requirement may vary based on age, region, and individual health status. Among various fibre-rich foods, wheat emerges as one of the best options, as it is a widely consumed staple food crop across many countries. Whole-wheat products provide a balanced mix of soluble and insoluble fibres required for better human health. Incorporating whole wheat into daily diets is a highly effective approach to meet the DF needs of a person.

Dietary Fibre

The word “fibre” originates from the Latin word “fibra,” which means “thread” or “filament.” The term “dietary fibre” was first used by Hipsley in 1953 while working on a disease called pregnancy toxaemia to describe the non-digestible parts of the plant cell wall. This was later modified by Trowell (1972, 1977) to include all non-digestible polysaccharides and lignin in the diet as well. After long years of scientific discussion, a well-structured definition of DF was elaborated by several globally recognized organizations, as shown in Table 1.

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Table No.1: Definition of DF as given by different organizations

ORGANIZATION	YEAR	DEFINITION	REFERENCE
Codex Alimentarius Commmission (FAO/WHO)	2009	Carbohydrate polymers with 10 or more monomeric units that are unable to be hydrolyzed in the small intestine.	Howlett et al., 2010
European Food Safety Authority (EFSA)	2010	Non-Digestible carbohydrates plus lignin, including non-starch polysaccharides, resistant oligosaccharides, resistant starch and lignin	EFSA, 2010
U. S. Food and Drug Administration (FDA)	2016	Non digestible carbohydrates (≥3 monomeric units) and lignin intrinsic of plants, as well as isolated or synthetic fibers with proven physiological benefits	FDA, 2018

Properties and health benefits of DF

Differentiation of DFs from other carbohydrates stems from its molecular size differences. Most DFs are carbohydrate in nature, with lignin being an exception. As per the definition, carbohydrates with ≥ 3 monomeric units that are not hydrolyzed in the small intestine are treated as DFs. The majority of these are structural polysaccharides making up the plant cell wall, like cellulose, hemicellulose (pentosans, xyloglucans, galactomannans, glucomannans, and β-glucans), and pectin (Selvendran et al., 1984). Alongside these come storage polysaccharides like resistant starches (RS1, RS2, RS3, and RS4) (BeMiller et al., 2020), non-starch polysaccharides (fructans), and lignin. These, again, are classified based on their solubility and origin (Fig. 1). Their physicochemical properties, such as solubility, viscosity, and fermentability, in turn, significantly influence their physiological effects and associated health benefits (He et al., 2022).

The degree of hydration and internal pH of DF determines its viscosity. Soluble DFs are classified into two types, i.e., random coiled DF and ordered assembly DF, depending on their degree of viscosity. Random coiled polysaccharides possess better viscosity owing to their random entanglement, especially longer-chain fibres due to increased molecular entanglement. The viscosity of dietary fibre plays an important role in human health by slowing gastrointestinal transit and enhancing satiety, thereby reducing postprandial lipaemia. Viscous fibre improves metabolic response and gives a prolonged feeling of fullness by delaying digestion and nutrient absorption by increasing luminal viscosity and water-holding capacity. Likewise, they also enhance colonic bulk and transit time, promoting regular bowel movements and overall gut health.

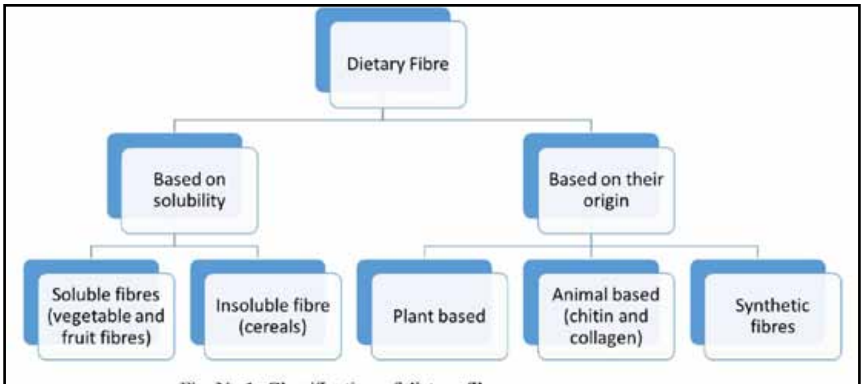


Fig. No.1: Classification of dietary fibers

The next significant characteristic feature of DF is its fermentability, which is influenced by viscosity, solubility, and accessibility to gut bacteria altogether. Certain gut microbes known as keystone species, which are primary degraders, play a crucial role in digesting fermentable fibres and releasing energy that is utilized by bacterial communities. This supports gut microbial diversity and promotes overall gut health by maintaining bacterial richness. A reduction in fermentable fibre intake over time can lead to changes in the gut microbiome, resulting in a loss of bacterial diversity and causing a condition called "Dysbiosis". This is often associated with gastrointestinal disorders, metabolic dysregulation, and immune dysfunction. DFs release short-chain fatty acids (SCFAs) like acetate, propionate, butyrate, and other minor SCFAs upon fermentation. Upon fermentation, DFs produce short-chain fatty acids (SCFAs) such as acetate, propionate, butyrate, and other minor SCFAs, which balance the gut microbiome composition and reduce many colon-related diseases (Wang et al., 2019).

Dietary Fibre in Wheat

Wheat is a staple food crop across the world, thereby serving as a primary source of carbohydrates, proteins, and a notable amount of DF. Wheat is a valuable source, offering both soluble and insoluble fibres. The wheat grain is anatomically composed of the endosperm, the germ, and the bran. Each of these contributes uniquely to the nutritional profile of wheat.

Approximately 83% of the wheat grain consists of the endosperm, which is predominantly made up of starch and proteins with small amounts of DF. This serves as the primary source of energy and is the main component in refined flour. The germ constitutes about 2–3% of the grain. The germ is rich in lipids, proteins, vitamins, minerals, and bioactive

Table No.2: DF profile of wheat grain

Component	Type	Percentage/Content (Shewry et al., 2023; Ma et al., 2022; Barron et al., 2020)	Grain Part
Total Dietary Fiber (TDF)	Both Insoluble & Soluble	9-20% (dry weight basis)	Whole Grain
Insoluble Dietary Fiber (IDF)	Major	Includes cellulose, hemicellulose, lignin (85-93%)	Bran, Aleurone Layer
Soluble Dietary Fiber (SDF)	Minor	Includes β-glucan, arabinoxylan (AX), and small amounts of glucomannans (5-9%)	Endosperm, Bran
Arabinoxylan (AX)	Major	Primary non-starch polysaccharide in wheat cell walls (water extractable 3-5%)	Bran, Aleurone Layer
β-Glucan	Soluble	Found in cell walls, but in lower amounts than in barley/oats (4-5%)	Endosperm, Bran
Cellulose	Insoluble	Less than 5% of wheat endosperm (25-32%)	Bran
Hemicellulose	Insoluble	Present in notable amounts (29-33%)	Bran, Aleurone Layer
Fructan	Soluble	Present but lower compared to rye (3-4%)	Endosperm, Bran
Lignin	Insoluble	Found in kernel outer layers (10-16%)	Bran, Pericarp

compounds. Though it contains some fibre, its contribution is relatively minor compared to the bran.

The bran comprises approximately 14–15% of the wheat grain. It is the outer covering of the wheat grain and is the richest source of dietary fibre, making whole-grain products an essential component of a fibre-rich diet. Bran consists of both soluble fibres (5–9%) (arabinoxylans and β-glucans) and insoluble fibres (85–93%) (cellulose, hemicellulose, and lignin) (Ma et al., 2022). Details of the fibres localized in different parts of the grain are listed in Table No. 2.

Refined Flour vs. Whole-Wheat Flour Dietary Fibre Content

The DF profile of different cereals is presented in Table No. 3 (Joye et al., 2020). Compared to other fibre-rich grains, wheat is one of the most preferred DF sources due to its high fibre content, affordability, and widespread consumption in various products like bread, pasta, and flour-based products. While grains like oats and rye have high fibre content, they are economically less efficient due to their higher cost, limited availability, additional processing needs, and lower consumer preference.

However, the typical wheat milling process removes nearly 80% of the total DF from wheat, reducing its fibre content from 13.3% in whole wheat to just 2.7% in refined flour (Serna et al., 2020). The American Association of Cereal Chemists (AACC) International (1999) provided a scientifically valid definition for whole grain: "Whole grains shall consist of the intact, ground, cracked or flaked caryopsis, whose principal anatomical components — the starchy endosperm, germ and bran — are present in the same relative proportions as they exist in the intact caryopsis."

Thereby, whole-wheat products retain all three components of the grain, making the dietary fibre available in larger quantities than in refined products, which lose the bran during milling, thus losing most of the fibre. This highlights the importance of using whole-meal, wheat-based products like chapatti, whole-grain bread, and pasta.

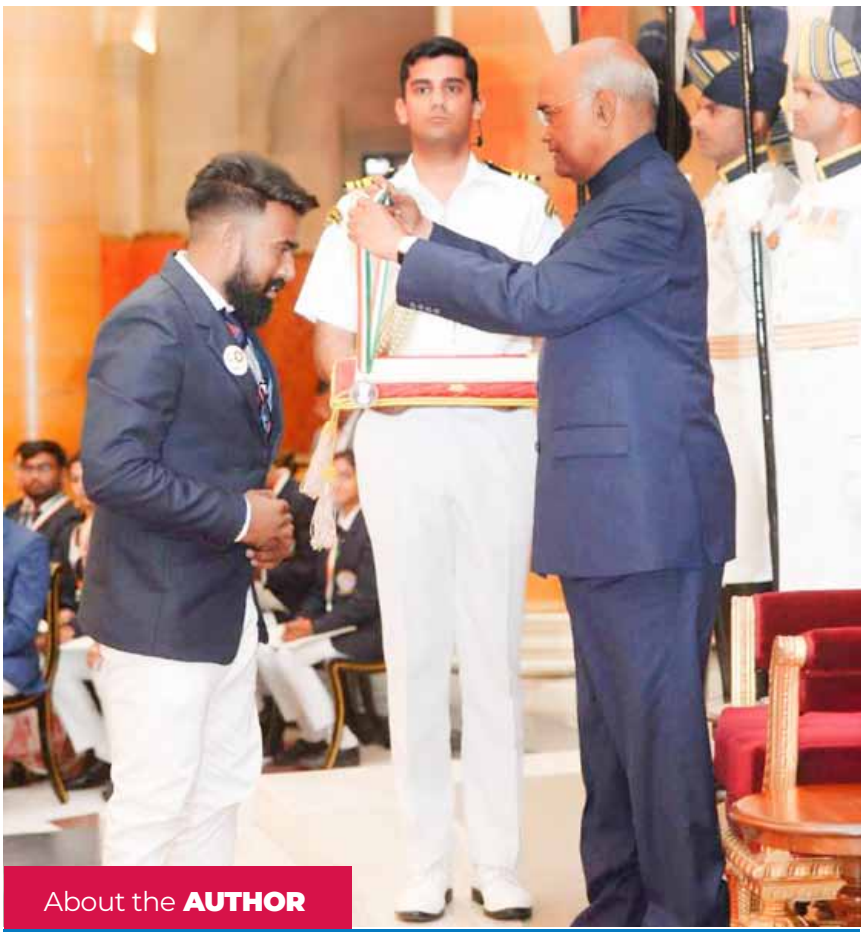
Insoluble wheat fibres, found primarily in the wheat bran and aleurone layer, promote gut health by adding bulk to stool and preventing constipation, diverticulosis, and irritable bowel syndrome (IBS) (Gill et al., 2021). Meanwhile, arabinoxylans and β-glucans slow carbohydrate digestion, regulating blood sugar levels and improving insulin sensitivity, which benefits individuals affected by diabetes (Chen et al., 2024). In addition, these aid in regulating cholesterol, reducing the onset of cardiovascular diseases by lowering LDL (bad cholesterol) absorption.

Wheat Fibre Supports Good Health

Wheat fibre has a prebiotic nature that supports a healthy gut microbiome by promoting beneficial bacteria that enhance digestion and overall metabolic health (Yu et al., 2023; Joye et al., 2020). Yu et al. (2023) reported that the incorporation of whole-meal flour into daily intake can lead to enhanced SCFA production, improved gut microbiome diversity, and reduced pathogenic bacterial growth. Hence, a simple shift from refined to whole-wheat flour can greatly enhance dietary fibre intake, supporting better overall gut health in human beings.

DF comprises non-digestible carbohydrates and lignin found in plant cell walls. It plays a key role in preventing many chronic health diseases by producing SCFAs and supporting gut microbiota. Wheat bran, in particular, is a significant source of DF. Whole-wheat flour retains all the components of the grain, making it much richer in fibre than refined flour. Hence, replacing refined products with whole-wheat options can enhance gut health by preventing digestive disorders.

PLANETARY PEDOLOGY
THE FUTURE OF SOIL SCIENCE BEYOND EARTH



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Mr Rohit Kumar is a Horticulture Development Officer and is currently a PhD Scholar at Department of Soil Science, Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar. He is a National Awardee and was awarded by the President of India in 2019 for social service and agricultural promotion. He is passionate about bridging the gap between traditional agricultural practices and modern scientific innovations

Planetary pedology represents an emerging frontier in soil science, focusing on the study and utilization of soil-like materials beyond Earth. As space exploration advances toward long-duration missions and extraterrestrial habitation, understanding the physical, chemical and biological properties of planetary regolith becomes essential. This article synthesizes current research on lunar and Martian soils, highlighting their limitations as growth media and exploring innovative strategies such as In-Situ Resource Utilization (ISRU), biological amendments and nanotechnology to transform these sterile substrates into productive systems. The study further examines classification challenges, geotechnical properties and the evolving definition of soil in extraterrestrial contexts. Ultimately, planetary pedology not only supports sustainable space colonization but also expands the conceptual boundaries of soil science within a broader planetary framework.

The Study Of Planetary Pedology

The exploration of extraterrestrial environments has entered a transformative phase, shifting from short-term missions to ambitions of permanent human settlement on the Moon and Mars. In this context, the study of planetary pedology (The science of soil-like materials beyond Earth) has gained critical importance. Traditionally, planetary surfaces such as lunar regolith were regarded as inert geological materials. However, recent research has redefined these materials as dynamic systems shaped by processes

such as space weathering, micrometeorite impacts and radiation exposure. This paradigm shift necessitates the adaptation of classical soil science frameworks, which were originally developed for Earth's biologically active systems. The absence of organic matter, liquid water and microbial life in extraterrestrial environments challenges conventional definitions of soil. Consequently, planetary pedology has emerged as a multidisciplinary field bridging geology, biology, engineeringand environmental science to support future space missions and habitation.

Conceptual Framework: Soil vs Regolith Debate

One of the fundamental challenges in planetary pedology lies in defining what constitutes "soil" beyond Earth. Traditionally, soil has been associated with biologically active layers supporting plant growth. However, modern perspectives argue for a broader definition that includes the entire weathered mantle or regolith, regardless of biological activity. This shift is reinforced by studies suggesting that soil and regolith form a continuous system extending from the surface to unweathered bedrock. In extraterrestrial environments, where biological processes are minimal or absent, this inclusive definition becomes particularly relevant. The debate highlights a transition from a purely biotic understanding of soil to one that emphasizes physical and chemical transformations, thereby expanding the scope of pedology to planetary scales.

Planetary pedology has emerged as a multidisciplinary field bridging geology, biology, engineering and environmental science to support future space missions and habitation

Classification of Extraterrestrial Soils

The classification of extraterrestrial soils presents another significant challenge. Existing systems such as the World Reference Base (WRB) and USDA Soil Taxonomy rely heavily on climate, vegetation and biological activity, these factors largely absent on the Moon and Mars.To address this gap, researchers have proposed novel classification frameworks tailored to planetary conditions. For instance, a lunar soil nomenclature introduces degree-symbol-prefixed horizons (°A, °B, °C, °D) based on parameters such as agglutinate content and maturity indices. This system allows for standardized mapping of lunar surfaces, which is essential for resource utilization and habitat planning. Such classification not only facilitates scientific understanding but also supports practical applications like construction, mining and agriculture in extraterrestrial environments.

Physical and Geotechnical Properties of Planetary Soils

Understanding the mechanical properties of extraterrestrial soils is crucial for mission safety and infrastructure development. Parameters such as grain size, cohesion and internal friction determine the stability of landing sites, rover mobility and construction feasibility.Recent advancements in penetrometry have enabled in situ analysis of regolith properties on planetary surfaces. These lightweight instruments provide reliable measurements of soil resistance and friction angles, offering a practical alternative to complex laboratory tests. Findings indicate that factors such as grain size significantly influence soil strength, while penetration velocity has minimal effect under certain conditions. These insights are vital for designing equipment and structures capable of operating in extraterrestrial environments.

Biological Potential and Limitations of Extraterrestrial Soils

Despite their classification as soil-like materials, extraterrestrial regoliths are inherently unsuitable for supporting life in their natural state. They lack essential components such as organic carbon, nitrogen and a functional microbiome. Additionally, extreme pH levels and potential toxicity further hinder biological

activity.Experimental studies have demonstrated that plant growth is possible in lunar and Martian simulants, but with significant limitations. For example, while some crops can germinate and grow, they often exhibit stress responses such as stunted growth and chlorosis. Nutrient deficiencies, particularly nitrogen and phosphorus, remain major constraints. These findings underscore the need for substantial modifications to transform regolith into viable growth media.

In-Situ Resource Utilization (ISRU) and Soil Transformation

In-Situ Resource Utilization (ISRU) has emerged as a cornerstone strategy for enabling sustainable extraterrestrial habitation. By utilizing locally available materials, ISRU reduces dependency on Earth-based supplies and supports long-term missions.Research indicates that the addition of organic amendments, such as compost or recycled waste, significantly improves the fertility of regolith. These inputs enhance nutrient availability, water retention and microbial activity, thereby creating conditions conducive to plant growth. Systematic reviews highlight that while raw regolith is incapable of sustaining life, targeted interventions can bridge this gap, transforming sterile substrates into productive agricultural systems.

Biological Engineering Approaches

a) **Role of Earthworms in Soil Formation**

Biological organisms play a crucial role in converting inert regolith into functional soil. Studies involving the earthworm *Eisenia fetida* demonstrate its ability to survive in regolith-organic mixtures and contribute to soil formation processes. Through burrowing and organic matter decomposition, earthworms enhance aeration, nutrient cycling and microbial activity.Although survival rates decrease in pure regolith, the introduction of organic substrates enables these organisms to thrive and reproduce. This highlights their potential as "bioengineers" in bioregenerative life support systems, facilitating sustainable agriculture in extraterrestrial environments.

As humanity ventures further into the cosmos, the ability to cultivate life from extraterrestrial soils will become a foundation of our survival and success beyond Earth

b) **Microbial and Fungal Symbiosis**

Microbial interactions, particularly those involving arbuscular mycorrhizal fungi (AMF), represent another promising avenue for soil transformation. These symbiotic relationships improve nutrient uptake, stabilize soil structure and enhance plant resilience under stress conditions.Remarkably, experiments have demonstrated successful seed production in chickpea plants grown in regolith simulants amended with AMF and vermicompost. These findings indicate that biological symbioses can overcome many of the inherent limitations of extraterrestrial soils, paving the way for sustainable food production systems.

Nanotechnology and Advanced Soil Amendments

In addition to biological approaches, nanotechnology offers innovative solutions for enhancing regolith fertility. The use of magnesium oxide-coated halloysite nanotubes (MgO-HNTs) has shown significant improvements in seed germination, root development and stress tolerance. These nanomaterials facilitate nutrient delivery and support early plant growth under extreme conditions. Interestingly, optimal concentrations vary depending on the type of regolith, reflecting differences in mineral composition and chemical properties. The integration of such advanced technologies into ISRU frameworks represents a cutting-edge approach to extraterrestrial agriculture.

Implications for Space Agriculture and Habitat Development

The successful transformation of extraterrestrial soils has profound implications for space exploration. Sustainable agriculture is essential for long-duration missions, providing food, oxygen and psychological benefits to astronauts.Beyond agriculture, understanding soil properties supports infrastructure development, including habitat construction and resource extraction. The ability to utilize local materials reduces mission costs and enhances self-sufficiency, making planetary colonization more feasible. Furthermore, the study of planetary pedology contributes to broader scientific knowledge, offering insights into planetary evolution and surface processes.

Challenges and Future Directions

Despite significant progress, several challenges remain in the field of planetary pedology. These include the lack of standardized methodologies, limited availability of high-fidelity simulants and the complexity of replicating extraterrestrial conditions on Earth.Future research must focus on interdisciplinary collaboration, integrating insights from soil science, microbiology, engineering and space science. The development of robust classification systems, advanced analytical tools and scalable soil transformation techniques will be critical for advancing the field.

Transformative Expansion Of Soil Science

Planetary pedology represents a transformative expansion of soil science, extending its principles beyond Earth to support the next era of human exploration. While extraterrestrial regolith presents significant challenges due to its sterility and nutrient deficiencies, innovative approaches such as ISRU, biological engineering and nanotechnology offer viable pathways for its transformation.By redefining the concept of soil and developing new frameworks for its study and utilization, planetary pedology not only enables sustainable space habitation but also enriches our understanding of Earth's own soil systems. As humanity ventures further into the cosmos, the ability to cultivate life from extraterrestrial soils will become a foundation of our survival and success beyond Earth.

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