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# Times of Agriculture

A Resonance in Agriculture  
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June-2026

## How NITARA is Helping Build the Missing Infrastructure in Global Livestock Systems

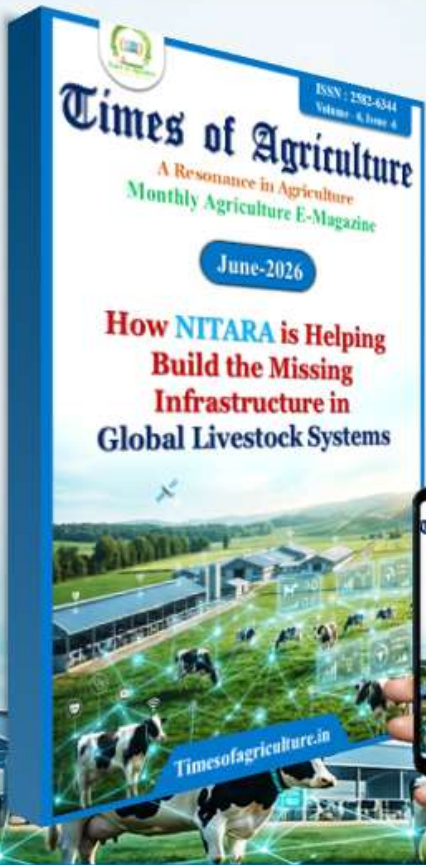


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**How NITARA is Helping Build the Missing Infrastructure in Global Livestock Systems**

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# AGRICULTURE UPDATES



## ICAR Demonstrates Biopolymer Seed Coating Technology for Groundnut Cultivation in Telangana

Groundnut cultivation in rainfed and semi-irrigated regions often faces challenges such as poor seed germination, vulnerability to seed- and soil-borne diseases, and inefficient use of agricultural inputs. Conventional seed treatment methods generally rely on a single-step application of chemicals, which can result in uneven distribution of protective agents and reduced compatibility with beneficial microorganisms. These limitations frequently affect crop establishment, plant growth and overall productivity, particularly under adverse environmental conditions. To overcome these issues, the ICAR–Indian Institute of Oilseeds Research (IIOR), Telangana, has developed an innovative biopolymer-enabled multilayer seed coating technology aimed at improving crop performance through targeted and controlled delivery of multiple crop inputs.

The newly developed technology uses a specially designed multilayer coating system that enables the application of beneficial microbes, biostimulants, micronutrients and reduced-dose chemical protectants in a structured manner. The coating architecture consists of a primer layer that provides strong adhesion to the seed surface, followed by additional functional layers carrying compatible crop inputs. This design allows spatially and temporally controlled release of the components, ensuring improved effectiveness and reducing the chances of incompatibility between biological and chemical agents. Researchers believe the technology can enhance seedling establishment, improve nutrient uptake and provide better protection against diseases during the critical early stages of crop growth.

Under ICAR’s Farmers FIRST Programme, the technology was demonstrated in groundnut fields at Rampur Thanda village in Telangana’s Vikarabad district. Demonstration plots used groundnut seeds coated with the functionally modified biopolymer multilayer system, while neighbouring plots followed conventional farmer seed treatment practices for comparison. Scientists involved in the project said the field demonstrations are intended to showcase the practical benefits of advanced seed technologies and encourage wider adoption among farmers. Experts believe the innovation could contribute to higher productivity, improved crop resilience and more efficient use of agricultural inputs, particularly in regions where groundnut cultivation is heavily dependent on rainfall and limited irrigation resources.



## Mother Dairy launches India's first naturally degradable milk pouch

Mother Dairy has introduced India's first naturally degradable milk pouch, marking a significant step toward sustainable packaging in the dairy industry. The company announced that the new packaging solution will be rolled out in the Delhi-NCR region beginning June 5, coinciding with World Environment Day, initially for its cow milk variant. Mother Dairy, a wholly-owned subsidiary of the National Dairy Development Board (NDDB), currently sells around 55 lakh litres of milk daily across several states. The company said the innovation aims to address growing concerns over plastic waste while maintaining the safety and quality standards required for milk packaging.

The newly developed pouch is based on degradable packaging technology that enables the material to break down naturally after disposal. According to the company, the packaging transforms into bioavailable wax, which is subsequently consumed by naturally occurring microorganisms in the soil and converted into harmless natural elements. Unlike conventional plastic, which can persist in the environment for hundreds of years, the new pouch is designed to degrade in soil within a few years. Company officials said the technology has been developed to reduce the long-term environmental impact of plastic packaging while supporting efforts to build a more sustainable and circular economy.

Mother Dairy emphasized that the new milk pouches will continue to be recyclable, ensuring compatibility with existing waste management systems. The key advantage, however, lies in their ability to degrade naturally if they escape formal collection and recycling channels. This feature is expected to help address the growing issue of "fugitive plastic," which refers to plastic waste that enters the environment due to inadequate disposal or waste management practices. Industry experts view the launch as a significant innovation in food-grade packaging and believe it could encourage wider adoption of environmentally responsible packaging solutions across the fast-moving consumer goods sector. The initiative also aligns with broader national efforts to reduce plastic pollution and promote sustainable consumption practices.



## Tamil Nadu Announces ₹134.83-Crore Kuruvai Special Package for Paddy Farmers

Tamil Nadu Chief Minister C. Joseph Vijay has announced a ₹134.83-crore Kuruvai Special Package to support paddy cultivation in the Cauvery delta region and other parts of the State. The package aims to boost agricultural productivity, improve water management and enhance the income of paddy farmers during the Kuruvai cultivation season. According to an official release, paddy is cultivated across 52.72 lakh acres in Tamil Nadu annually. Of this, 20.65 lakh acres are located in the Cauvery delta region, which includes Thanjavur, Tiruvarur, Nagapattinam and Mayiladuthurai districts, along with parts of Cuddalore, Tiruchi and Ariyalur districts. On average, around 5.14 lakh acres in the delta region are cultivated during the Kuruvai season each year.

The State government has earmarked ₹77.5 crore for the Cauvery delta districts and ₹57.33 crore for paddy-growing areas in other districts. Outside the delta region, paddy cultivation is carried out on approximately 32.07 lakh acres annually, with nearly 5.48 lakh acres cultivated during the Kar, Kuruvai and Sornavari seasons. The announcement coincided with the customary opening of the Mettur dam on June 12, a crucial event that ensures the availability of irrigation water for Kuruvai cultivation in the delta districts. Officials said the special package has been designed to provide timely support to farmers and encourage efficient use of available water resources.

The government stated that the package will focus on promoting agricultural mechanisation, strengthening water conservation measures and improving overall farm productivity. Officials believe the initiative will help reduce cultivation costs, increase operational efficiency and improve returns for farmers. The scheme is also expected to contribute to higher paddy production, supporting Tamil Nadu's food security objectives. Agricultural experts welcomed the announcement, noting that timely assistance during the Kuruvai season is essential for sustaining paddy cultivation in the Cauvery basin. The package is expected to benefit thousands of farmers across the State while reinforcing efforts to maintain stable foodgrain production and strengthen the agricultural economy.



## ICAR-CIBA Develops Fish Waste-Based Bio-fertilisers for Sustainable Farming and Aquaculture

Scientists at the Chennai-based ICAR-Central Institute of Brackishwater Aquaculture (CIBA) have developed an innovative biofertiliser technology derived entirely from fish market waste, offering a sustainable and cost-effective alternative to conventional fertilisers. The institute has introduced two new products — CIBA-PlanktonPlus and CIBA-HortiPlus — designed to convert fish processing waste into valuable agricultural and aquaculture inputs. Researchers said the technology addresses two major challenges simultaneously: the scientific disposal of large quantities of fish waste and the increasing demand for environmentally friendly nutrient sources that improve soil fertility and productivity. The development is expected to support sustainable agriculture and aquaculture while promoting the circular economy by turning waste into a valuable resource.

According to scientists, India produces nearly 195 lakh tonnes of fish annually, generating more than 60 lakh tonnes of fish waste. Much of this waste remains underutilized and can create environmental concerns if not managed properly. Researchers estimate that this resource has the potential to produce around 48 lakh tonnes of CIBA-PlanktonPlus and nearly 3 lakh tonnes of CIBA-HortiPlus every year. The products are designed to enrich nutrient availability, improve biological activity and support healthier crop and aquatic production systems. By converting fish waste into biofertilisers, the technology provides an opportunity to reduce dependence on chemical fertilisers while creating additional value from the fisheries sector.

Extensive multi-location on-farm trials conducted in Andhra Pradesh, West Bengal, Gujarat, Kerala, Tamil Nadu and Odisha demonstrated promising results, particularly for aquaculture applications. Scientists reported that the use of CIBA-PlanktonPlus in fish and shrimp ponds increased production by 0.6 to 0.8 tonnes per hectare, improved survival rates by 10 to 15 percent and reduced feed requirements by 20 to 50 percent. Researchers believe these benefits can significantly lower production costs while improving profitability for fish and shrimp farmers.



## CSIR-IICT's Biomethanation Technology Converts Vegetable Waste into Green Energy

The CSIR-Indian Institute of Chemical Technology (CSIR-IICT) has developed an innovative high-rate biomethanation technology based on the Anaerobic Gas Lift Reactor (AGR), offering an efficient solution for managing biodegradable waste while generating renewable energy. The technology gained national recognition after receiving a special mention by Prime Minister Narendra Modi during his Mann Ki Baat address in January 2021. One of its most successful implementations is at the Dr B. R. Ambedkar Vegetable Market Yard in Bowenpally, Secunderabad, the largest vegetable market in Hyderabad. The market generates nearly 10 to 12 tonnes of vegetable waste every day, creating a significant waste management challenge that is now being addressed through the AGR-based biogas plant established within the premises.

The in-house biogas facility, with a processing capacity of 10 tonnes of waste per day, converts vegetable waste into approximately 500 to 600 cubic metres of biogas daily. The generated biogas is further used to produce nearly 500 units of electricity every day, helping meet the market's energy requirements through a sustainable source. In addition, a portion of the biogas is utilized in the market canteen, replacing around 30 kilograms of liquefied petroleum gas (LPG) each day. The project demonstrates how organic waste generated in urban markets can be transformed into valuable energy resources instead of being sent to landfills. Officials say the initiative not only reduces waste disposal problems but also contributes to lower energy costs and improved environmental management.

CSIR-IICT scientists developed the Anaerobic Gas Lift Reactor as a high-rate biomethanation system specifically suited to Indian conditions. The technology efficiently converts biodegradable organic waste into biogas and nutrient-rich bio-manure through a scientifically controlled process.



## Centre Launches Nationwide Khet Bachao Abhiyan to Promote Soil Health and Sustainable Farming

Union Minister for Agriculture and Farmers Welfare and Rural Development Shivraj Singh Chouhan has launched the nationwide Khet Bachao Abhiyan from Ramasiya village in Madhya Pradesh's Raisen district. The month-long campaign, running from June 1<sup>st</sup> to June 30<sup>th</sup>, 2026, aims to promote soil health conservation, balanced fertilizer uses and sustainable agricultural practices across the country. The launch event witnessed the participation of farmers, scientists, agricultural experts, administrators and extension workers, highlighting a collective effort to safeguard agricultural productivity through improved soil management. Officials said the campaign is focused on encouraging farmers to adopt scientific and environmentally responsible farming methods that can enhance crop yields while preserving natural resources.

The campaign seeks to address the growing concern over excessive use of chemical fertilizers, particularly urea, which has led to nutrient imbalances, declining soil fertility, groundwater contamination and increasing subsidy burdens. Under the initiative, farmers will be encouraged to adopt soil test-based nutrient management and make greater use of Soil Health Cards for informed fertilizer application. The programme also promotes natural farming, balanced nutrient use, green manuring, improved seed varieties, seed treatment techniques and water-efficient cultivation practices. Agricultural experts involved in the campaign believe these measures can improve soil quality, reduce input costs and strengthen long-term agricultural sustainability. Special emphasis is being placed on modern sowing methods and water conservation practices to help farmers cope with changing climatic conditions and resource constraints. In addition to promoting sustainable farming, the Khet Bachao Abhiyan will create awareness about counterfeit fertilizers, seeds and pesticides that often affect farm productivity and farmer incomes.



## PM Narendra Modi Receives FAO's Prestigious Agricola Medal 2026

Prime Minister Narendra Modi has been honoured with the prestigious Agricola Medal 2026 by the Food and Agriculture Organization (FAO) of the United Nations in recognition of his contributions to food security, sustainable agriculture and rural development. The award was presented by FAO Director-General Dr. Qu Dongyu during a ceremony held at the FAO Headquarters in Rome. The honour acknowledges Prime Minister Modi's leadership in advancing agricultural transformation, improving farmer welfare and strengthening global efforts to address hunger and poverty. FAO officials stated that the award also recognizes India's growing role in promoting sustainable and resilient agrifood systems on the international stage.

Accepting the award, Prime Minister Modi dedicated the recognition to India's farmers and the agricultural scientific community, crediting them for the country's achievements in ensuring food security and nutrition. He highlighted several initiatives undertaken to modernize Indian agriculture, including the 'Per Drop More Crop' programme, expansion of micro-irrigation, precision farming techniques and the adoption of advanced technologies. The Prime Minister also emphasized the increasing use of artificial intelligence-based advisory systems, agricultural drones, remote-sensing technologies and sensor-based machinery to improve productivity and resource efficiency. According to officials, these measures have contributed to making Indian agriculture more sustainable, climate-resilient and technology-driven. FAO noted that the Agricola Medal recognizes Prime Minister Modi's continued support for the organization's mission of combating hunger, reducing poverty and advancing the United Nations Sustainable Development Goals. The award also acknowledges his efforts to place agrifood systems, food security and rural development at the forefront of global discussions, including during India's G20 Presidency.



# **How NITARA is Helping Build the Missing Infrastructure in Global Livestock Systems**

## About the Author

**Mr. Manish Jain**

Founder - **NITARA**

*(A digital dairy intelligence platform)*



The next revolution in livestock will not come from producing more animals.

It will come from building better systems around them.

Systems that detect disease before it spreads.

Systems that guide breeding decisions before losses occur.

Systems that allow veterinarians, farmers, financial institutions, and policymakers to operate from the same source of truth.

Across the world, governments and investors are increasingly recognising that the future of animal health depends not only on science and infrastructure, but also on digital systems capable of connecting fragmented ecosystems.

This emerging consensus was evident at the World Organisation for Animal Health (WOAH) General Session in Paris, where global leaders gathered to discuss how innovation and digitalisation can de-risk investments and strengthen livestock systems for the future.

In May 2026, global leaders in animal health, public policy, finance, and livestock systems convened in Paris for the 93rd General Session of the World Organisation for Animal Health (WOAH). Widely regarded as one of the most influential platforms in the animal health ecosystem, the forum brought together government representatives, multilateral institutions, development agencies, and industry stakeholders to address some of the most pressing challenges facing global livestock systems.

Among the distinguished participants at this year's Animal Health Forum was Mr. Manish Jain, Founder of Nitara—a digital dairy intelligence platform—who was invited as a panellist for a high-level discussion on:

**“Innovation and digitalisation of animal health services to de-risk investments.”**

His participation marked a significant moment not just for the company, but for India's rapidly evolving agri-tech ecosystem. Notably, Nitara was the only private-sector dairy technology platform represented at the forum, standing alongside global institutions such as the World Bank Group, Heifer International, Hunland Group, and WOAH delegates.

## Why This Moment Matters

The WOAH General Session is not merely a conference—it is a decision-shaping platform where global standards, priorities, and collaborative frameworks for animal health are discussed and influenced. The inclusion of a private-sector agri-tech player like Nitara reflects a broader shift in how innovation is being perceived within the livestock ecosystem.



For decades, animal health systems have been largely driven by public-sector interventions and policy frameworks. However, the increasing complexity of challenges—from disease outbreaks and climate volatility to farmer income instability—has highlighted the need for scalable, technology-driven solutions that can operate at the grassroots level.

This is where platforms like Nitara are beginning to play a transformative role.

## **A Shift Towards Digital Animal Health Systems**

The central theme of the panel—digitalisation of animal health services—underscores a growing global consensus: future-ready livestock systems must be data-driven, predictive, and inclusive.

Traditional livestock management practices often rely on fragmented data, delayed interventions, and limited access to advisory services, especially for smallholder farmers. These inefficiencies not only impact productivity but also increase systemic risks, making investments in the sector more uncertain.

Digital platforms, on the other hand, enable real-time monitoring, data-backed decision-making, and proactive health management. By integrating farm-level data with advanced analytics, they can significantly reduce risks associated with disease outbreaks, productivity losses, and market fluctuations.

At the forum, discussions highlighted how such innovations are not just improving operational efficiency but also making the livestock sector more attractive for institutional investments.

## **Nitara's Role in Redefining Dairy Intelligence**

Nitara's presence at WOAHA was driven by its unique positioning within the global agri-tech landscape.

At its core, Nitara is designed to serve small and mid-sized dairy farmers—an often-underserved segment that forms the backbone of milk production in countries like India. By combining a digital platform with on-ground interventions, the company has developed a comprehensive ecosystem that addresses multiple aspects of dairy management.

## **What sets Nitara apart is its integrated approach.**

Beyond software, the platform is complemented by innovative hardware tools and diagnostic kits that deliver measurable improvements in farm productivity within a short span—often within a single quarter of deployment. These tools enable farmers to track animal health, optimise feeding practices, and detect issues early, thereby reducing losses and improving overall efficiency.



This combination of digital intelligence and physical infrastructure creates a powerful feedback loop—one where data continuously informs action, and action generates more data for refinement.

### **Bridging the Gap for Smallholder Farmers**

One of the key reasons for WOA's interest in Nitara lies in its focus on smallholder farmers.

Globally, a significant portion of dairy production comes from farmers who operate on a small scale, often with limited access to veterinary services, financial resources, and technical knowledge. Despite their importance, these farmers remain highly vulnerable to risks—from disease outbreaks to fluctuating market prices.

Nitara's model directly addresses this gap.

By simplifying complex data into actionable insights, the platform empowers farmers to make informed decisions on breeding, nutrition, and health management. This not only improves individual farm productivity but also contributes to the resilience of the broader dairy ecosystem.

Importantly, these improvements are achieved in a sustainable manner—ensuring that gains in productivity do not come at the cost of animal welfare or environmental health.

### **Advancing Genetic Intelligence in Dairy**

Among Nitara's most notable innovations is its work in genetic intelligence.

The platform has mapped a significant portion of the cattle gene pool in India—an achievement that enables highly targeted breeding recommendations. Using advanced algorithms, Nitara can identify optimal genetic matches for cattle, helping farmers avoid inbreeding and improve the quality of future generations.

The implications of this are profound.

By enhancing genetic outcomes, farmers can achieve up to a 30% increase in the profitability of the next generation of livestock. This not only boosts income but also strengthens long-term sustainability, as healthier and more productive animals require fewer resources and are less prone to disease.

In the context of global discussions on food security and resource efficiency, such innovations are particularly relevant.



## De-Risking Investments Through Technology

A central theme of the WOAHA panel was the need to de-risk investments in the livestock sector.

Investors and financial institutions often perceive agriculture—and livestock in particular—as high-risk due to its exposure to biological, environmental, and market uncertainties. This perception has historically limited the flow of capital into the sector, especially in emerging markets.

Digital platforms like Nitara are beginning to change this narrative.

By providing transparent, real-time data on farm performance, animal health, and productivity metrics, they reduce information asymmetry and enable better risk assessment. This, in turn, makes it easier for investors to evaluate opportunities and for farmers to access credit and insurance.

At the forum, discussions emphasised that such data-driven ecosystems are essential for unlocking large-scale investments in livestock systems.

## India's Growing Influence in Global Dairy Innovation

India's position as the world's largest milk producer makes it a critical player in global dairy discussions.

However, the country's dairy sector is unique—characterised by millions of smallholder farmers rather than large industrial operations. This structure presents both challenges and opportunities.

Innovations that succeed in India—by working effectively at scale within a fragmented ecosystem—have the potential to be replicated across other developing regions facing similar conditions.

Nitara's participation at WOAHA is a reflection of this potential.

It signals that solutions emerging from India are not only addressing domestic challenges but are also contributing to global conversations on animal health, sustainability, and agricultural resilience.



## A Collaborative Future for Animal Health

The WOAH General Session highlighted the importance of collaboration across sectors. Governments, international organisations, private companies, and farmers all have a role to play in building resilient livestock systems. While policy frameworks provide direction and support, innovation from the private sector brings agility and scalability.

Nitara's inclusion in this dialogue demonstrates the growing recognition of such partnerships.

By working alongside global institutions, agri-tech companies can help translate high-level strategies into on-ground impact—ensuring that solutions reach the farmers who need them most.

### Looking Ahead

The conversations at the WOAH Animal Health Forum 2026 made one thing clear: the future of livestock systems will be shaped by the intersection of technology, data, and collaboration.

As challenges continue to evolve, so too must the approaches used to address them.

Nitara's participation in this global forum is not just a milestone for the company—it is an indication of the direction in which the industry is moving. A direction where innovation is inclusive, data is actionable, and growth is sustainable.

For India's agri-tech ecosystem, it represents an opportunity to lead—not just in production, but in shaping the future of dairy worldwide.

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## POST-HARVEST LOSSES AND LIMITED PROCESSING ACCESS: THE MISSING LINK IN INDIA'S AGRICULTURAL GROWTH



About Author  

**Mr Vicky Dodani**  
Co-founder- Agrizy

India grows food on a scale that ought to be the envy of the world. Yet far too much of that abundance never reaches a plate in a form that holds its value, its nutrition, or the farmer's dignity. Post-harvest losses and the thin reach of processing are not technical footnotes. They are

the quiet, daily erosion of rural incomes, the reason a good season can still leave a family exposed, and the structural gap that stops the country from converting farm output into higher-value products and lasting prosperity.

Recent national assessments continue to show losses that vary sharply by crop and by region. Fruits and Vegetables, perishable and roughly handled, suffer the most, with wastage for some commodities running anywhere from 5 to 16 percent. The annual bill is now valued at over ₹1.5 lakh crore. Yet, despite these losses, food insecurity has declined, with undernourishment falling to 14 percent compared to 20 percent in 2010.

The human cost is intimate. A farmer who has nursed a crop

for months gets a narrow window to sell it. With no processing or cold storage within reach, the only realistic move is to sell fast, at whatever the market will pay that day. Call it a distress sale, but it is not a glitch a single subsidy can correct. It is the predictable result of a system that parks processing capacity and quality infrastructure far from where the food is actually grown.

Policy, to its credit, has tried. Over the past decade, schemes for cold storages, pack houses and primary processing units have been launched and scaled, supported by public investment and financing initiatives. Yet access to processing and quality infrastructure remains limited across many agricultural clusters. As a result, a significant share of



produce continues to move through the value chain with limited opportunities for preservation, value addition or market diversification.

Closing the gap means rethinking processing as something distributed and modular, planted next to production clusters rather than miles away. A small unit that can sort, grade, wash, process and preserve produce at the village or cluster level rewrites the economics of farming. Beyond reducing losses, it creates opportunities for value addition closer to the farm, allowing agricultural produce to move beyond raw commodity markets and into higher-value supply chains. It lets a grower time the sale, reach higher-value buyers, and join chains that actually pay

for quality and consistency. When processing sits close by, losses can be cut by up to 50 %, and farmers can earn 20-30 % more by avoiding distress sales. The incentive to invest in better agronomy and careful handling rises, because the payoff is visible and quick.

Access to finance remains important, but capital alone is rarely enough. Small processors and farmer groups also need operational capabilities, market linkages and reliable demand to build sustainable businesses. The models that endure are those that combine financing with technical support and market access, ensuring that processing capacity translates into real economic value.

In my view, the missing link in India's growth story is not

production alone but the ability to create more value from what is already produced. Reducing post-harvest losses is important, but the larger opportunity lies in bringing processing and value addition through production clusters, supported by accessible financing and stronger market linkages. When farmers gain access to these capabilities, they are not just preserving produce for longer, they are improving quality, accessing better markets and capturing a greater share of the value created after harvest. The reward is not abstract. It has stronger rural incomes, more resilient supply chains and a food ecosystem that converts abundance into lasting prosperity.





## TECHNOLOGICAL INTERVENTION OF ARTIFICIAL INTELLIGENCE (AI) IN INDIAN AGRICULTURE



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**A**griculture plays a major role in the economic development of India. For the past decades, the farmers

have been using traditional techniques and methods to increase productivity yields. Since then, the increase in population means more demand for increasing food production. The manual intensity of farming practices significantly affects arithmetic productivity rates. AI technology has recently emerged in India and the agriculture and farming sector is one area that can utilize the advantages of the AI technology. AI agriculture is the future of smart farming; a technology that can power the economy using predictive technology that will ease the way for farmers in getting information about the weather and fertile land conditions for optimum productivity levels. AI and precision farming can revolutionize the agricultural sector in other to reach and meet the goals of productivity demands to secure the country's future.

With the emergence of Artificial Intelligence (AI), precision farming, digital advice, remote sensing, drones and crop insurance remedies, Indian agriculture is poised to undergo a revolution. These technologies are designed with innovative approaches to increase productivity, improve climate resilience, minimize resource waste and empower farmers with data-driven decision-making. In partnership with government initiatives and innovations through scientific institutions, Indian agriculture is steadily evolving for sustainable development.

India's economy is still significantly impacted by Agriculture, which is a source of living, food security, and rural development. Nonetheless, again the climate change, water shortages, deterioration of soil



fertility, pest infestation, tiny land plots, and fluctuating markets have negative effects on the farmers. India has been steadily moving toward the digitalization-based technologies and complete analytics to address these issues. Innovations in the fields of Artificial Intelligence, precision agriculture, geospatial engineering industry and digital governance platforms are opening new avenues to transform agriculture. This permits the farmers the efficient usages of inputs, increasing yields and improving resilience to unpredictable and uncertain climate and market factors.

### **Precision agriculture: The foundation of smart farming**

Precision agriculture is a scientific technique where high technology is used to optimize outcrop production. Unlike traditional farming techniques, precision farming uses up-to-date data to make precise field-based decisions. Farmers determine their crops' health status, soil quality, nutrient availability, and irrigation needs with the help of technologies like satellite images, drones, Internet of Things (IoT) sensors, GPS mapping and Geographic Information Systems (GIS). This allows them to administer the right amount of water, fertilizer and pesticides in an efficient manner with reduced cost and lower impact on the environment. In India, successful precision farming programs have

been shown to improve crop yields, improve water-use efficiency, and enhance profitability for all farms.

### **Artificial Intelligence in agriculture**

The growing importance of Artificial Intelligence in agricultural innovations, AI systems possess the capacity to systematically evaluate the enormous amount of agricultural data and transform it into valuable insights while providing information to farmers, researchers, and policymakers. The applications of AI are in crop disease detection, pest detection, yield prediction, weather forecasting, irrigation planning, and market information. The machine learning models will learn the hidden patterns in the agricultural data and will provide localised recommendations. Artificial Intelligence-powered advisory systems are assisting farmers in choosing appropriate sowing time, fertilizer application time, harvesting time, and mitigation of risks etc. The productivity-enhancing effects of AI technologies are expected to rise rapidly as these technologies gain traction.

### **Climate resilience and sustainable agriculture**

Agriculture is greatly affected by climate variability, possibly the current-day biggest threat to its sustainability. Droughts, floods, heat waves, and unpredictable rains have great impacts on crop production and farmers' livelihood. Farmers are

receiving coaching and assistance through cutting-edge forecasting systems, satellite-based monitoring, and AI-based climate analysis to deal with harsher weather. Early-warning systems help critically in early warning of adversary weather situations and pest infestation and thus, preventive measures can be taken at the earliest. Technology encourages sustainable agriculture practices for conserving natural resources. Its advanced irrigation systems, precision nutrition competence, and data-driven farming ensure growth while minimizing environment-pressure.

### **PMFBY and tech-driven risk management**

PMFBY is arguably the world's largest crop insurance scheme. The main objective of this scheme is to provide financial assistance to the farmers in case of unexpected crop loss due to natural disasters. The advancements in technology have also greatly transformed the landscape of crop insurance. Currently, there is a growing trend in the use of remote sensing, geo tagging, drones, satellite imaging, and mobile applications to monitor crops and assess damages. These techniques are aimed to introduce transparency in the system, expedite the claim process, and install confidence among the farming community in crop insurance. The use of digital technology with crop insurance will ensure the socio-economic



stability and sustainable rural development of Indian agriculture. The use of digital technology with crop insurance will ensure the socio-economic stability and sustainable rural development of Indian agriculture.

### **Role of scientific institutions and innovation ecosystems**

The research and scientific ecosystem in India contribute significantly to the evolution of agrarian transformation. The research organizations, universities, start-ups, innovation centres, government agencies are focusing on creating the necessary solution for dealing with the local challenges in agriculture. Innovations such as AI-driven advisory platforms, smart irrigation systems, automatic pest detection devices, precision nutrient management systems, and drone-based crop health monitoring tools. Innovations are paving the way for the convergence of research outcomes with farm practices. Partnerships across sectoral boundaries among government agencies and tech creation communities would spur the growth and incorporation of using frontier technology in farming.

### **Digital agriculture and farmer empowerment**

There is empowerment of farmers with the help of digital

technologies and modern agricultural methods. Forecast of weather, information about the markets, advisory on crops, government schemes, insurance and financial products can be accessed through mobile applications and online platforms. Digital technologies enhance the availability and accessibility of agricultural information and knowledge, thus, allowing farmers to make informed decisions based on factual data. Besides, rapidly increasing mobile phone access and internet connections in villages encourage technology usage and digital technology-based agricultural extension services. Agriculture's digital transformation improves efficiency and also fosters financial inclusion and market access.

### **Challenges and future outlook**

Even after progress had been made, there are still few challenges. Lack of digital infrastructure, unaffordability, lack of awareness, and lack of skill are barriers to technology adoption, especially to small and marginal farmers. Going forward, ensuring the digital infrastructure, improving the farmers' capacity building, ensuring enthusiasts partnership between the private sector and public sector, and coming up with affordable localized solutions should be prioritized. Investments in

research, innovation, and capacity building will be instrumental in ensuring that inclusive growth in agriculture is realized. We will have to infuse the experience of agri-value and supply chain, science-based technologies with centuries of knowledge, to build the new-age agriculture systems for sustainability, resilience and farmers at the centre.

### **Conclusion**

The application of Artificial Intelligence, Precision farming, Digital agriculture, and technology-enabled crop insurance are transforming Indian agriculture. These developing technologies are enabling farmers to increase productivity, judicious use of resources, risk management, and increasing income. With joint efforts between the farmers, scientists, policymakers, industry and development stakeholders, the agriculture sector in India is indeed on its way towards a technological transformation. With more investment in terms of research and development in accordance with innovative technologies, India will achieve a sustainable agricultural system that can cope up with the challenges of food security and sustainability in the present and the future.





# FROM TINY INSECTS TO BILLION-DOLLAR BUSINESS: INDIA'S BIOLOGICAL CONTROL REVOLUTION

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Every year Indian farmers spend thousands of crores on chemical pesticides to protect crops from insect pests and diseases. However, growing concerns regarding pesticide residues, resistance development, environmental contamination, and consumer demand for safe food are driving a major shift towards biological control. Tiny beneficial organisms such as parasitoids, predators, microbes, and entomopathogenic nematodes are increasingly becoming the backbone of sustainable crop protection, creating a rapidly expanding biological control industry in

India. The industry is currently valued at over USD 2 billion and is expected to expand steadily in the coming years as farmers and exporters increasingly seek residue-free crop production systems. The Indian market for biological control agents is witnessing consistent growth and is projected to reach nearly USD 2.8 billion by 2031. This expansion is driven by increasing awareness of sustainable pest management, rising organic farming practices and stringent residue regulations imposed by

international markets. Export-oriented crops, particularly fruits, vegetables, spices, cotton, and sugarcane, are among the major beneficiaries of biological control technologies. Among the various biocontrol products available, microbial agents such as predators and parasitoids account for a significant share of field-level applications. Their effectiveness, affordability, and compatibility with integrated pest management (IPM) programs have contributed to their widespread adoption.

**Important Biological Control Agents**

Biological Agent	Target Pest/Disease	Major Crops
<i>Trichogramma spp.</i>	Stem borers, bollworms	Sugarcane, Cotton
<i>Chrysoperla spp.</i>	Aphids, whiteflies	Vegetables, Cotton
<i>Cryptolaemus montrouzieri</i>	Mealybugs	Fruits
<i>Bacillus thuringiensis</i>	Caterpillars	Vegetables
<i>Trichoderma viride</i>	Soil-borne pathogens	Multiple crops
<i>Heterorhabditis indica</i>	Soil insects	Horticultural crops



## Success stories

Biological control has already demonstrated remarkable success in India. The release of *Trichogramma chilonis* in sugarcane and cotton ecosystems has significantly reduced stem borer and bollworm infestations. Similarly, *Cryptolaemus montrouzieri*, popularly known as the "mealybug destroyer," has been successfully utilized in fruit crops and plantations for suppressing mealybug populations.

## Research, development, and regulatory support

The advancement of biological control technologies in India is strongly supported by research institutions and regulatory agencies. The ICAR-National Bureau of Agricultural Insect Resources (NBAIR) plays a central role in developing, evaluating, and promoting biological control agents suited to different agro-climatic regions. Through collaboration with

numerous State Agricultural Universities, region-specific strains and production technologies are continuously being refined and disseminated. On the regulatory front, agencies such as the Central Insecticides Board and Registration Committee (CIBRC) have introduced mechanisms to facilitate the registration and commercialization of biological products. Recent initiatives have also simplified the approval process for indigenous microbial strains, encouraging innovation and private-sector participation.

## Industry structure and major players

The biological control industry in India consists of a diverse network of public-sector laboratories, small and medium-scale manufacturers, and multinational companies. Domestic firms such as T. Stanes & Company, KN Bio Sciences, and Sonkul Agro Industries have

made significant contributions to the production and distribution of biological control products. International companies, including Koppert Biological Systems and BASF, have also expanded their presence in the Indian market by introducing advanced biological solutions and technologies.

## Policy support and government initiatives

The growth of India's biological control industry is being strengthened by supportive government initiatives promoting sustainable agriculture. Programs such as the National Mission on Natural Farming and Integrated Pest Management (IPM) initiatives are encouraging the adoption of biological inputs and reducing dependence on synthetic pesticides. In addition, increasing emphasis on residue-free agricultural exports is creating new opportunities for bio-based crop protection products, further accelerating the demand for biological control technologies.

## Emerging trends and future prospects

Despite impressive growth, challenges remain in meeting the increasing demand for biological control agents, particularly during peak cropping seasons. Production capacities of many public-sector facilities are often insufficient to supply large-scale agricultural requirements. Nevertheless, the sector is evolving rapidly. Innovations such as automated insectaries, advanced fermentation systems,

### CAREER AND ENTREPRENEURSHIP OPPORTUNITIES IN INDIA'S BIOLOGICAL CONTROL INDUSTRY



Figure 1. Major career and entrepreneurship opportunities emerging from India's rapidly expanding biological control industry.





support, technological advancements, and growing farmer awareness, biological control is expected to become a cornerstone of sustainable agricultural production in India.

India's biological control industry stands at a critical juncture where scientific innovation, environmental necessity, and market demand are converging. With increasing emphasis on sustainable agriculture, residue-free food production, and climate-resilient farming systems, biological control agents are poised to become indispensable components of crop protection strategies. Strengthened research, quality assurance, policy support, and farmer awareness will determine how effectively this sector contributes to the future of Indian agriculture.



and improved formulations are enhancing the quality and shelf life of bioagents, while drone-based applications and digital pest monitoring tools are making their use more efficient in the field. Growing investments in indigenous bioagent development, digital agriculture, and precision farming technologies are further

expanding market opportunities and strengthening the commercial viability of biological control products. These innovations are not only strengthening sustainable pest management but also creating promising avenues for agri-startups in biological input production, advisory services, and technology-driven crop protection solutions. With continued policy





# INSECT DIGITAL TWINS: THE NEXT FRONTIER OF PREDICTIVE ENTOMOLOGY AND SMART PEST MANAGEMENT

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**M**odern agriculture is entering an era where digital technologies are transforming every aspect of crop production. Artificial intelligence, remote sensing, robotics and Internet of Things (IoT) devices are increasingly being integrated into farming system to improve productivity and sustainability. Despite these

advances, insect pests continue to cause substantial crop losses worldwide due to their rapid adaptation, high reproductive potential and ability to exploit changing environmental condition.

Current pest management strategies largely depend on monitoring existing infestations and responding after pest populations reach economic thresholds. Such reactive approaches often result in delayed intervention; increased pesticide use and reduced effectiveness of control measures. Future agriculture requires predictive system capable of forecasting pest

outbreaks before visible damage occurs.

A revolutionary concept that could reshape entomology is the development of Insect Digital Twins. An insect digital twin is a dynamic virtual replica of a real insect population that continuously receives biological, environmental, behavioral and climatic information from the field. By simulating insect growth, reproduction, dispersal and interactions with crops in real time, digital twins could predict pest outbreaks, optimize management decisions and support sustainable agriculture.

## What is an Insect Digital Twin?

A digital twin is a virtual model that accurately represents a physical object or system. In engineering, digital twins are already used to monitor aircraft engines, manufacturing plants and smart cities. Applying this concept to entomology involves creating a digital replica of an insect species that continuously updates itself using field data.

The digital twin would include:

1. Life cycle characteristics
2. Developmental thresholds
3. Reproductive rates
4. Feeding behavior
5. Movement patterns
6. Host plant interactions
7. Natural enemy relationships
8. Weather responses
9. Resistance evolution.

Instead of merely recording pest population, the system would predict future pest behavior under changing environmental condition.

### Climate change adaptation in Insect Digital Twin system

Climate change is significantly influencing insect distribution, survival, reproduction and seasonal activity, creating new challenges for pest management. Insect digital twin system can address these challenges by integrating real-time biological data with future climate projections to predict pest behavior under changing environmental condition. These virtual models simulate how temperature,

rainfall, humidity and other climatic factors affect insect development, population growth and geographic spread.

For example, the invasive pest Fall Armyworm has expanded into several new regions due to rising temperatures and favorable climatic condition. An insect digital twin could combine climate forecasts with the pest's developmental biology to predict future distribution, population peaks and outbreak risks. Similarly, warmer winters may allow pests that were previously restricted by low temperatures to survive and establish in new agricultural areas.

Digital twins can also forecast changes in voltinism (number of generations per year). If increasing temperatures enable a pest to complete an additional generation during a cropping season, the system can estimate the resulting increase in infestation pressure and recommend timely management interventions.

By predicting future pest scenarios years in advance, climate-adaptive digital twins can support surveillance programs, guide crop planning, strengthen biosecurity measures and help develop long-term strategies for sustainable and climate-resilient agriculture.

### Digital Twin-Based Resistance Management

Pesticide resistance is a major threat to sustainable pest management, reducing the

effectiveness of insecticides and increasing crop losses. Insect digital twin system can help manage resistance by simulating resistance gene frequencies, selection pressure, mutation emergence and the spread of resistant populations under different management scenarios. These virtual models allow researchers to conduct risk-free experiments before field implementation. For example, a digital twin of the red spider mite or fall armyworm could evaluate the long-term effects of insecticide rotation, refuge strategies, biological control agents, or RNAi-based technologies. The system would identify the most effective resistance management strategy and provide farmers with scientifically optimized recommendations.

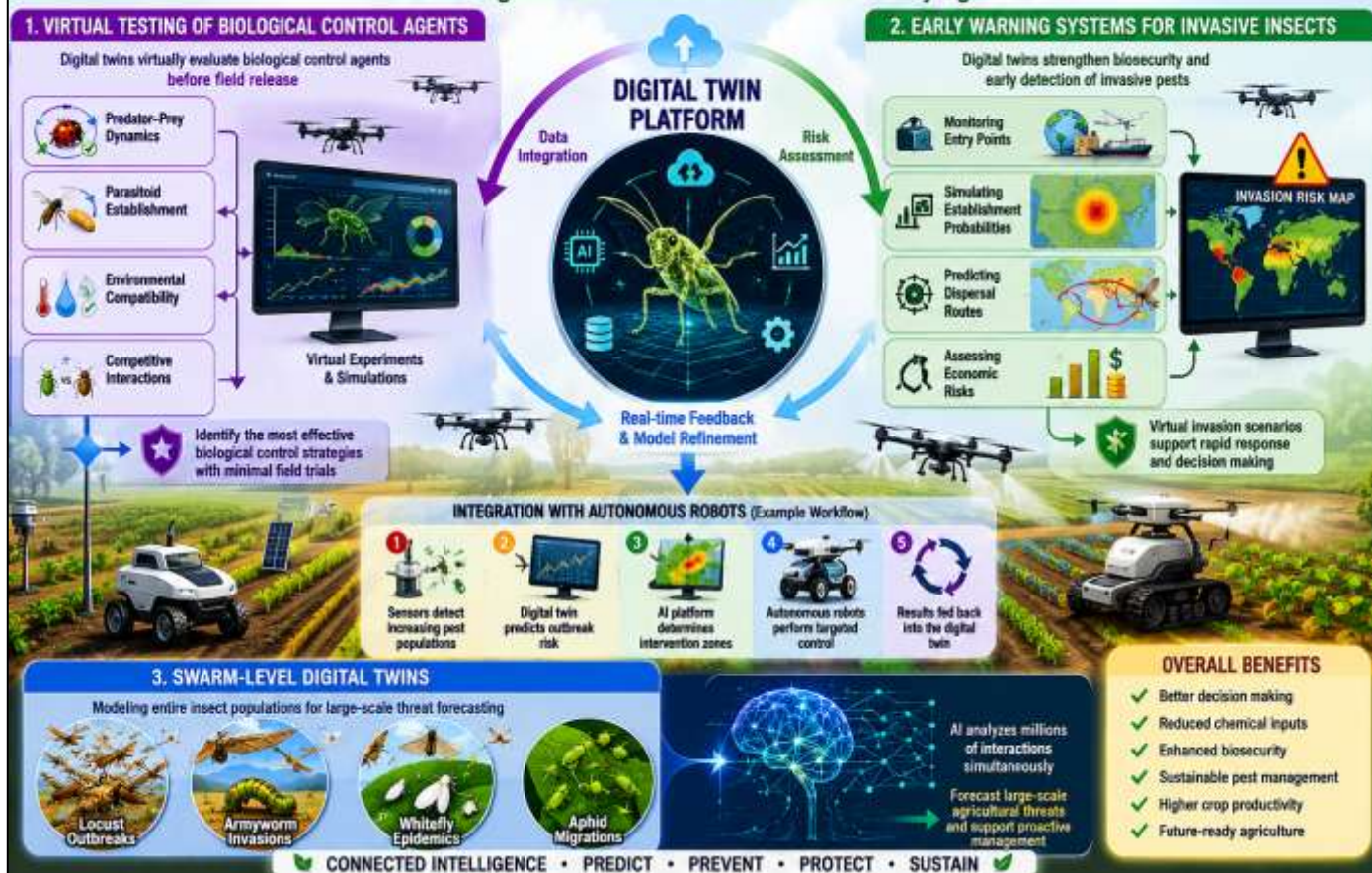
### Integration with Autonomous Agricultural Robots

Future smart farms may integrate insect digital twins with autonomous agricultural robots to achieve highly precise and sustainable pest management. In this system, field sensors continuously monitor pest populations and transmit data to the digital twin, which analyzes the information and predicts potential outbreak risks. Artificial intelligence then identifies specific areas requiring intervention and generates targeted management recommendations. Autonomous ground robots or drones can subsequently perform localized



# INTEGRATION OF ADVANCED INSECT DIGITAL TWIN APPLICATIONS

Virtual Intelligence for Sustainable and Future-Ready Agriculture



control measures such as precision pesticide application, biological control release, or mechanical pest removal. The effectiveness of these interventions is fed back into the digital twin, allowing continuous model refinement and improved decision-making. This closed-loop system minimizes unnecessary pesticide use, reduces environmental impact, lowers production costs and enhances the efficiency of integrated pest management programs.

## Quantum-Enhanced Entomological Simulation

Future computational system may utilize quantum computing to process complex biological interactions.

Quantum-assisted digital twins could simulate:

- Gene-environment interactions
- Population evolution
- Host adaptation
- Ecosystem dynamics

Such capabilities would dramatically improve prediction accuracy.

## Digital twin laboratories

Future advances in entomology may lead to the development of Digital Twin Laboratories, where virtual insect populations complement traditional insectaries and experimental facilities. These laboratories would use highly sophisticated digital twin models that accurately replicate insect biology, genetics, physiology,

behavior and ecological interactions under diverse environmental condition. By integrating artificial intelligence, computational biology and real-time field data, researchers could conduct virtual experiments to evaluate the effectiveness of emerging pest-management technologies before undertaking costly and time-consuming field trials.

Digital twin laboratories could simulate the impacts of novel insecticides on target and non-target organisms, assess the efficacy of RNA interference (RNAi)-based pest control strategies, predict the ecological consequences of gene-editing approaches and optimize sterile insect technique (SIT) programs



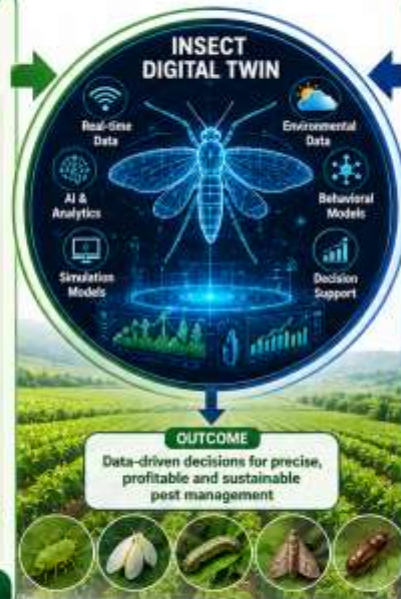
# INSECT DIGITAL TWINS: BENEFITS & CHALLENGES FOR SUSTAINABLE AGRICULTURE

Smart Modeling Today for a Sustainable Tomorrow

## BENEFITS FOR SUSTAINABLE AGRICULTURE

- EARLIER PEST DETECTION**  
Real-time monitoring and predictive analytics enable early detection and timely interventions.
- REDUCED PESTICIDE CONSUMPTION**  
Targeted applications based on accurate predictions minimize chemical usage.
- LOWER PRODUCTION COSTS**  
Optimized pest management reduces input costs and increases profitability.
- IMPROVED BIOLOGICAL CONTROL**  
Simulations help select and deploy the most effective natural enemies.
- ENHANCED CLIMATE RESILIENCE**  
Models predict pest responses to climate variability and support adaptive strategies.
- BETTER RESISTANCE MANAGEMENT**  
Digital twins simulate resistance evolution and evaluate strategies to delay resistance.
- INCREASED CROP PRODUCTIVITY**  
Healthier crops through precise, timely, and science-based pest management.
- REDUCED ENVIRONMENTAL CONTAMINATION**  
Minimized off-target effects protect ecosystems, biodiversity and human health.

These benefits support global sustainable agriculture goals including food security, environmental protection and resilience.



## CHALLENGES AND FUTURE RESEARCH NEEDS

- MASSIVE DATA REQUIREMENTS**  
Digital twins require large, high-quality datasets from diverse sources over time and space.
- SENSOR STANDARDIZATION**  
Lack of standardized sensors and protocols limits data interoperability.
- MODEL VALIDATION**  
Models must be rigorously validated across species, environments and conditions.
- COMPUTATIONAL INFRASTRUCTURE**  
High-performance computing resources are needed for complex simulations and AI.
- DATA SECURITY CONCERNS**  
Protecting sensitive data and ensuring privacy and cybersecurity are critical.
- FARMER ACCESSIBILITY**  
Tools must be user-friendly, affordable and accessible to smallholder farmers.
- INTERDISCIPLINARY COLLABORATION**  
Integration of entomology, AI, data science, agronomy, engineering and social sciences is essential.

Addressing these challenges through research, innovation and collaboration will enable real-world impact.

## FUTURE RESEARCH: TOWARDS NEXT-GENERATION DIGITAL TWINS



by modeling population suppression under different release scenarios. In addition, researchers could investigate insect responses to projected climate-change condition, including elevated temperatures, altered rainfall patterns and extreme weather events. These virtual experiments would enable rapid screening of multiple management options, identification of potential risks and refinement of intervention strategies. Promising technologies demonstrating high efficacy and environmental safety in digital

simulations could then proceed to targeted greenhouse and field validation, thereby accelerating innovation while reducing research costs, experimental uncertainty and ecological risks.

### Conclusion

Insect Digital Twins represent a visionary yet scientifically achievable future for entomology. By creating continuously updated virtual replicas of pest populations, researchers and farmers could move from reactive pest control to predictive pest intelligence. Such system would enable real-

time forecasting, precision interventions, climate adaptation planning, resistance management and sustainable crop protection. As agriculture embraces artificial intelligence and smart farming technologies, insect digital twins may emerge as one of the most transformative innovations in twenty-first-century entomology, fundamentally changing how insect pests are monitored, understood and managed across global agricultural system.



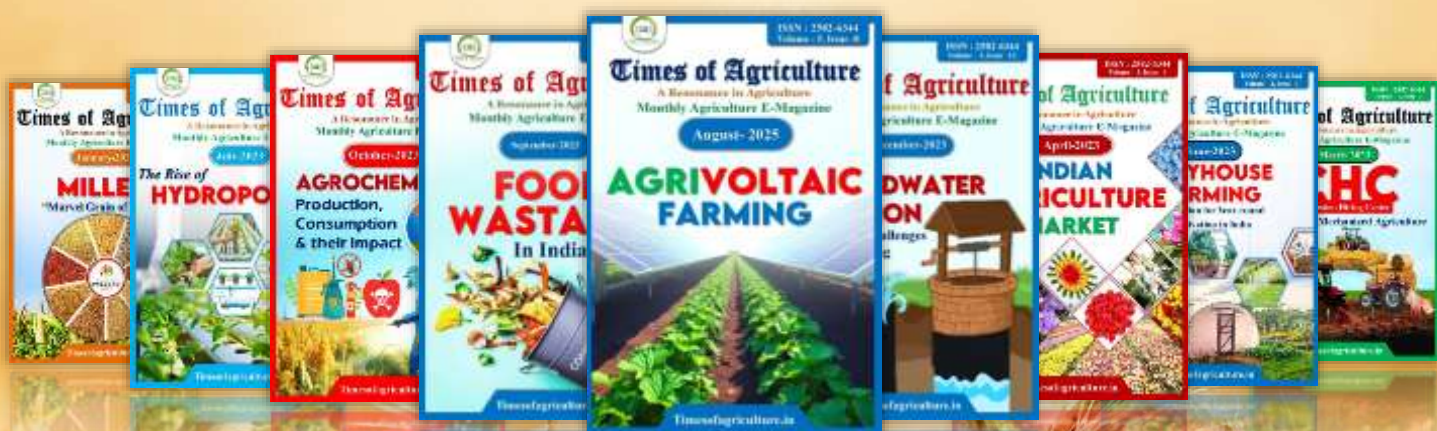


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