

Seeds of progress

Advancing global trade, innovation and sustainable agriculture

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Foreword by Assocham

The agriculture sector remains central to India's vision of achieving Viksit Bharat@2047, with the seed industry serving as the foundation of agricultural productivity, food security, and rural prosperity.



Mr. Saurabh Sangal
Secretary General,
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Over the years, India has emerged as one of the world's leading seed markets, supported by a strong scientific ecosystem, progressive research institutions, entrepreneurial enterprises, and a diverse agricultural landscape.

As global agriculture undergoes rapid transformation, the future of the seed sector will be shaped by innovation, technology, climate resilience, digital agriculture, and sustainable farming practices. Advances in plant breeding, hybrid seed development, gene editing, precision agriculture, and agri-tech solutions are creating unprecedented opportunities to enhance crop productivity, improve farmer incomes, and address emerging food security challenges.

Today, the sector requires not only robust seed production and distribution systems but also greater investments in research and development, stronger public-private partnerships, enhanced regulatory preparedness, and wider adoption of emerging technologies. Equally important is ensuring that innovation reaches farmers effectively, enabling sustainable and climate-resilient agricultural growth.

This report **Seeds of progress: Advancing global trade, innovation and sustainable agriculture** presents key perspectives on the trends, opportunities, and strategic priorities

shaping the future of India's seed ecosystem. The report highlights developments in global seed trade, biotechnology, climate-resilient agriculture, regulatory frameworks, innovation ecosystems, and policy interventions necessary to strengthen India's position as a global leader in seed research, production, and trade.

At ASSOCHAM, we remain committed to fostering constructive engagement among industry, government, research institutions, academia, and other stakeholders, while advancing policy recommendations that promote innovation, competitiveness, sustainability, and inclusive growth across the agricultural value chain.

I congratulate and thank the industry leaders, policymakers, researchers, scientists, and all contributors associated with this important initiative. I hope this report will serve as a valuable knowledge resource and contribute meaningfully towards strengthening India's seed sector and advancing sustainable agricultural development in the years ahead.

Foreword by Grant Thornton Bharat

Agriculture remains central to food security, livelihoods and economic resilience, yet the priorities shaping its future are evolving across markets.



Priyank Bhardwaj
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Grant Thornton Bharat

Emerging economies continue to focus on productivity, farmer incomes and access to quality inputs, while mature markets are increasingly driven by sustainability, traceability, climate resilience and resource efficiency. Together, these shifts are reshaping the global seed industry.

Seeds are now far more than a cultivation input. They are a strategic enablers of productivity, nutrition security, climate adaptation and sustainable agriculture. In this context, competitiveness will be defined by the ability to develop superior genetics, accelerate innovation, assure quality and deliver improved varieties reliably to farmers and markets.

India stands at a pivotal moment in this transition. As the fifth-largest seed market globally, the country is supported by a strong public research base, growing private-sector participation, established seed production ecosystems and a large domestic market. These strengths align closely with the broader visions of Viksit Bharat @2047 and Atmanirbhar Bharat.

However, scale alone will not define leadership. India's participation in global seed trade remains below its underlying production potential, indicating a gap between capability and value capture. Closing this gap will require stronger investment in advanced breeding, molecular tools, quality systems,

regulatory efficiency, public-private collaboration and last-mile delivery.

India's agro-climatic diversity creates a unique advantage for breeding, testing and seed production across cereals, pulses, oilseeds, cotton and horticulture crops. Combined with expanding innovation capacity and regional market access, this positions India to emerge as a seed innovation and supply hub for Asia and Africa, particularly as climate stress increases demand for resilient varieties and more dependable seed systems.

This report outlines a way forward for translating India's scale and diversity into innovation depth, export competitiveness and resilient seed systems. The task ahead is clear — to build a globally competitive seed ecosystem that strengthens farmer prosperity, enhances national resilience and contributes meaningfully to global food security.

Executive summary

This thought leadership paper discusses changes in the global seed industry from a volume-led input business to an innovation-led, genetics-intensive ecosystem. It covers the global seed landscape, India's position in trade and value capture, innovation and breeding technologies, climate-resilient seed systems, regulatory and trade barriers, public private partnership (PPP) models, key industry challenges, strategic opportunities and an action agenda for India.

The central message is clear: future seed leadership will be determined not by market size alone, but by the ability to develop superior genetics, move them efficiently through regulatory and trade systems, and deliver them reliably to farmers.

Key insights: Global seed value is increasingly concentrated in innovation-led segments such as vegetable seeds, hybrids, proprietary genetics and licensed breeding material. Industry statistics estimate global seed exports at approximately USD 16.2 billion in 2022, while India's HS 1209 exports of around USD 127.7 million represented less than 1% of global export value, highlighting India's value-capture gap despite its production strength. Climate resilience has also become a core industry priority. A global seed-sector survey in 2024, indicated that nearly 45% of respondents ranked climate change as the most challenging issue facing the sector, while trade, seed movement and regulation were also repeatedly cited as constraints. Extreme heat is already a major agricultural risk, with FAO-WMO reporting that a single heatwave can reduce agricultural productivity by up to 50% in severe conditions.

Strategic opportunity for India: India has the foundations to become a regional seed innovation and supply hub for Asia and Africa: diverse agro-climatic zones, public and private breeding capability, established seed production clusters, a large domestic market and growing scientific talent. The

strongest opportunity lies in moving beyond volume production toward high-value seed segments: vegetable and horticulture seeds, hybrids, pulses, oilseeds, forage crops and climate-resilient dryland crops. Similar agro-ecologies across South Asia, Southeast Asia, East Africa and West/Central Africa create demand for affordable, resilient and productivity-enhancing seed solutions. The proposed India Seed Trade & Innovation Summit also positions India around seed innovation, exports, regulatory harmonisation, climate resilience and PPPs.

Positioning India as a global seed innovation and export hub

- 1 Scale advanced breeding technologies including molecular breeding, genomic selection, gene editing, speed breeding, digital phenotyping and Artificial Intelligence-enabled breeding analytics to shorten the 10–15-year varietal development cycle and improve genetic gain.
- 2 Target high-value export segments, especially vegetable seeds, hybrid seeds, pulses, oilseeds, forage crops and climate-resilient dryland crops, where India can combine production capability with emerging demand in Asia and Africa.
- 3 Modernise seed regulation and trade facilitation by streamlining variety registration, strengthening traceability and quality assurance, and aligning more closely with OECD, ISTA, IPPC and SPS-based systems to reduce trade friction.
- 4 Strengthen public-private licensing and commercialisation pathways so that publicly developed germplasm, parental lines, hybrids and traits can move faster into market-ready seed products. TAAS-ICAR-FSII-NSAI discussions emphasise PPPs, equitable value sharing and private-sector investment as key to scaling agricultural innovation.
- 5 Develop climate-resilient seed systems, not only climate-resilient varieties. India should prioritise drought-tolerant, heat-resilient, pest-resistant, early maturing and resource-efficient varieties while ensuring last-mile seed access in rainfed, dryland, tribal and climate-vulnerable regions.

A photograph of three seedlings at different stages of growth emerging from dark, rich soil. The seedling on the right is the tallest, with a large, light-brown seed coat still attached to its green cotyledons. The middle seedling is smaller, with two green leaves visible. The seedling on the left is the smallest, with a single green leaf. The background is a soft, out-of-focus green. Overlaid on the image are several thin, white, curved lines that create a sense of movement and design.

Global seed landscape and India's position in the ecosystem



The global seed industry is undergoing a structural transformation. Recent market estimates project the global seed market to be between **USD 70–80 billion in 2024**, with projections crossing **USD 100 billion by 2030**. More importantly, seeds are no longer viewed only as an agricultural input; they are becoming a **strategic lever for productivity, food security and climate adaptation**.

Crop improvement and the delivery of high-quality seed are central to improving crop production and meeting environmental challenges.

As food demand rises, climate risks intensify and natural resource constraints deepen, seeds are playing an increasingly important role. Crop improvement and the delivery of high-quality seeds are now central to improving agricultural productivity and enabling resilient production systems. This shift is redefining competitiveness in the seed industry. The industry is moving from a paradigm of producing more seed toward one focused on developing, protecting and deploying superior genetics faster.

1.1 Innovation-led seed segments are driving value creation

The global seed industry is highly diverse, spanning **more than 300 seed species** across crops, geographies and production systems. However, it is structurally segmented between **volume-driven crops and value-driven segments**.

Cereals and oilseeds form the **volume base** of global seed systems, driven by their scale in food production. In contrast, **vegetable and horticulture seeds account for a disproportionately high share of trade value despite relatively small volumes**, reflecting their higher genetic complexity, hybridisation levels and commercial intensity.

Other segments such as spices, forage crops, flowers and specialty seeds add further diversity, but the central structural characteristic of the global seed market remains clear:

Value in global seed trade is increasingly concentrated in innovation-led, genetics-intensive segments rather than volume-driven crops.

This dynamic is further reinforced by the growing importance of **biotechnology, hybridisation and advanced breeding tools**, which are increasing the value intensity of high-performance seed categories.

1.2 Global demand is splitting by market maturity

Global seed demand and trade are increasingly differentiated by market maturity and role in the value chain.

- **Mature markets** (e.g., the Netherlands, the US, France, Germany) dominate value capture through innovation, IP and export networks
- **Emerging markets** (e.g., China, India, Brazil, Turkey) are driving demand growth through rising imports and agricultural expansion
- **ASEAN and Africa/MENA markets** are evolving as hybrid zones, with growing demand and selective export capabilities

Global seed demand and export capability are split between mature value-capture hubs and emerging growth markets

Global seed demand and export capability are split between mature value-capture hubs and emerging growth markets

Market archetype	Key regions	Trade snapshot (USD)	Trade and market implication
Mature/Innovation and re-export hubs	The Netherlands, the US, France, Germany, Spain, Italy, Denmark	Imports: USD3.53 billion (NL: USD 0.89 billion, USA: USD 0.64 billion) Exports: USD 6.47 billion (NL: USD 2.7 billion, USA: USD 1.07 billion) Vegetable seeds: Exports: USD 4.01 billion (NL: 2.38 billion, FR: USD 0.63 billion)	Global value leaders Strong in breeding, IP, and re-export networks Segment focus: Broad sowing seeds, vegetable seeds, re-exported seed lots, breeding material, certified seed
Large emerging markets	China, India, Brazil, Turkey, Pakistan	Imports: USD 1.02 billion (China: USD 0.46 billion, India: USD 0.17 billion) Exports: USD 0.49 billion (China: USD 0.19 billion, India: USD 0.15 billion) Vegetable seeds: Imports USD 0.64 billion; Exports USD 0.35 billion (China: 0.17, India: 0.12)	Demand-driven markets Growing exports but low value capture Segment focus: Vegetable seeds, hybrid seeds, productivity-enhancing varieties, formal seed systems, climate-relevant genetics
ASEAN production nodes	Thailand, Philippines, Indonesia, Malaysia, Singapore, Cambodia, Myanmar	Imports: USD 0.12 billion (PH: USD 0.04 billion, TH: USD 0.03 billion) Exports: USD 0.18 billion (PH: USD 0.16 billion, TH: USD 0.14 billion) Vegetable seeds: Exports USD 0.14 billion (TH: USD 0.12 billion), Imports USD 0.09 billion	Regional hubs Strong in vegetable seed production Segment focus: Vegetable seeds, horticulture seeds, regional multiplication, hybrid adoption
Africa / MENA Demand Markets	Morocco, Egypt, South Africa, Kenya, Algeria, Tanzania, Uganda, Mozambique, Senegal, Tunisia	Imports: USD 0.53 billion (Morocco: USD 0.15 billion, Egypt: USD 0.12 billion) Exports: USD 0.20 billion (South Africa: USD 0.12 billion) Vegetable seeds: Imports USD 0.37 billion, Exports USD 0.14 billion (South Africa: 0.09, Kenya: 0.02)	High-demand regions Select export nodes (South Africa, Kenya) Segment focus: Vegetable seeds, horticulture, climate-adapted seeds, formal seed system expansion

The data shows that mature seed markets dominate value capture, particularly in vegetable seeds, through strong breeding systems, IP, certification, re-export networks and global distribution. Emerging markets, however, are no longer peripheral: China, India, Brazil, Turkey, ASEAN and Africa/MENA markets show meaningful import demand, particularly for vegetable seeds. This creates a clear distinction between demand growth and value capture, a theme that becomes central to India's opportunity.

Parallely, global seed trade is evolving beyond the simple movement of commercial seeds to movement of genetics, germplasm and innovation assets. Modern seed systems are increasingly driven by cross-border flows of breeding material,

multi-location testing, seed multiplication and technology licensing. This shift is enabled by:

- Harmonised certification systems
- Phytosanitary standards
- Plant variety protection (PVP) frameworks

Industry consolidation has created a smaller group of integrated players combining seeds, biotechnology and crop protection capabilities, transforming the industry into globally networked innovation ecosystems. As a result, seed trade is no longer defined only by the movement of seed, but by access to genetics, technology platforms and innovation networks.

The next question is not only where seed demand is growing, but who captures value from genetics, certification and export networks.

Note: Imports and exports data presented in the table refers to trade data for HS Code 1209 (seeds, fruit and spores used for sowing). Vegetable seeds trade data refers to trade data for HS Code 120991 (vegetable seed used for sowing). Values are rounded to USD billion. EU aggregate has been excluded from market baskets to avoid double counting with individual EU countries.

1.3 Five structural forces shaping global seed competitiveness

The basis of competition in the seed industry is shifting from scale to innovation speed, adaptability and ecosystem strength.

Five structural forces shaping global seed competitiveness

Force	01  Diverging agricultural priorities	02  Climate as a commercial constraint	03  Innovation speed advantage	04  Trade moving from seed to genetics	05  Ecosystem-driven competitiveness
What is changing	Emerging markets focus on productivity; mature markets shift to resilience and sustainability	Yield stability, drought tolerance and adaptability now determine varietal success	Gene editing, genomics and AI are compressing breeding cycles	Germplasm, traits and R&D pipelines moving across borders	Integrated research, policy, production and commercialisation systems matter more
Implication	Demand drivers differ, but all markets are converging towards better genetics	Resilience traits are becoming core to commercial competitiveness	Winning firms/ countries will be those that reduce time-to-market	Value lies in IP and innovation networks, not just physical seed trade	Competitive advantage shifts from firms to national ecosystems

Across these forces, a clear pattern emerges — competitive advantage is shifting from production scale to the ability to innovate, adapt and commercialise rapidly within integrated ecosystems. While seed demand is increasingly global, value capture remains concentrated in markets with strong innovation, IP and distribution capabilities. As a result, countries are no longer competing simply as producers or markets, but as coordinated systems that combine research, regulation, production and commercialisation. This raises a critical question for large agricultural economies: Can they move beyond being demand centres to becoming value creators in high-value, innovation-led seed segments?

Against this backdrop, India is emerging as one of the most strategically positioned seed ecosystems globally. Ranked as the fifth-largest seed market globally, the Indian seed industry has expanded from approximately USD 2.75 billion in 2014 to USD 4.25 billion in 2023–24 driven by rising seed replacement

rates, increasing hybridisation and increased adoption of improved varieties, particularly in vegetables. Looking ahead, the market is expected to reach USD 6 billion, with an additional USD 1 billion potential from exports, even as current trade remains skewed towards volume participation rather than value capture. As one of the world’s largest agricultural economies, India sits at the intersection of global demand growth and evolving value chains, making it critical to assess how its domestic ecosystem, trade profile and innovation capabilities align with emerging global patterns.

India is no longer merely a large seed market; it is emerging as one of the world’s most strategically positioned seed ecosystems. This expansion has been driven by rising seed replacement rates in key crops (rice, wheat, soybean), increasing hybridisation in crops such as cotton, maize and mustard, and wider adoption of improved varieties of vegetable seeds.

1.4 India’s seed system architecture

India’s seed ecosystem was built to solve three agricultural challenges — **food security, productivity enhancement, and resilience**. The seed ecosystem has, therefore, evolved around a **functional specialisation between public research and private enterprise**, shaped by these priorities.

Public institutions, led by **Indian Council of Agricultural Research (ICAR) and State Agricultural Universities**, have focused on staple crops such as rice, wheat and pulses, ensuring varietal development aligned with national food security objectives. In parallel, private seed companies have driven innovation and commercialisation in hybrid crops such as cotton, maize, sunflower and vegetables — segments characterised by high value, rapid innovation cycles and strong market orientation.

This division has created a system that simultaneously supports **large-scale public-good breeding** and market-driven innovation, enabling India to expand hybrid adoption, strengthen commercialisation pathways and scale seed systems across diverse crop segments. Hybrid seeds, in particular, have historically provided a natural mechanism for protecting breeding investments, encouraging sustained private-sector participation even before intellectual property frameworks reached maturity.



1.5 India’s position in global seed trade

India is an active participant in the global seed trade, but its position reflects a **structural gap between volume participation and value capture**.

Recent estimates indicate that India remains a net importer of seeds, with exports estimated at approximately USD 127.7 million compared to imports of USD 168.2 million. Export activity is concentrated across a limited set of markets, led by the US (29%), followed by the Netherlands (13%), with additional flows to regional markets such as Bangladesh, Vietnam and Nepal. On the import side, sourcing is concentrated, with China (31%), Thailand (12%) and the Philippines (9%) accounting for a significant share, alongside imports from the Netherlands and the US.

India remains a marginal player in global seed exports. As compared to global seed exports of approximately USD 16.2 billion, India’s HS 1209 exports of USD 127.7 million represented less than 1% of global export value.

This gap becomes particularly visible when benchmarking India against established seed hubs. While India exports seed volumes comparable to leading exporters such as the Netherlands, the value realised per unit remains significantly lower. For instance:

India vs Netherlands in terms of volumes vs value of exports - 2024

	Metric	
	Export volume (million Kg)	Export value (USD million)
 India	12.8	122
 Netherlands	11.9	2,377

Despite similar volumes, the Netherlands captures nearly 20 times higher export value, reflecting its dominance in high-value segments such as vegetable seeds, proprietary genetics and licensed breeding material.

India’s current position is that of a large and growing market with production strength, but with limited value capture in global seed trade.

1.6 India's cluster-based model of competitiveness and regional seed hubs

India has begun to establish a presence in vegetable seed exports, indicating early movement toward higher-value segments. However, this remains at a nascent stage compared to global leaders. India's current trade profile therefore reflects a system that is integrated into global markets but not yet positioned as a value-capturing hub.

India's global relevance is anchored in a unique combination of structural strengths that few countries possess simultaneously. The country spans 15 major agro-climatic zones, enabling breeding, testing and commercialisation across cereals, oilseeds, cotton, vegetables, pulses and horticultural crops. This diversity allows seed companies and research institutions to conduct multi-location trials, validate varietal performance and scale production within a single geography reducing reliance on cross-border testing networks.

In addition, India hosts a **complete seed value chain**, encompassing:

Research and
germplasm
development

Breeding
and varietal
improvement

Seed
multiplication
and production

Processing,
certification and
distribution

This public-private ecosystem is supported by a **large domestic market**, an established base of private seed companies, and widespread farmer participation, creating both scale and continuity in seed demand. India's strength lies not in any single capability, but in the **co-existence of scale, diversity and end-to-end execution within one ecosystem**.

India's seed ecosystem operates through a **network of specialised regional hubs**, each contributing distinct capabilities to the national system.

Among these, **Telangana stands out as the most prominent example**, widely recognised as India's "**Seed Bowl**." Its emergence was initially driven by favourable agro-climatic conditions for hybrid seed production. Over time, this advantage attracted a dense network of seed companies, processing infrastructure, specialised farmer groups and research institutions, resulting in a self-reinforcing ecosystem.

Other regions complement this model:

Andhra Pradesh

Strong field crop
seed production

Karnataka

Vegetable seeds
and private-
sector breeding

Maharashtra

Diversified
horticulture and
seed systems

Punjab and Haryana

Cereal breeding
and public-sector
systems

Together, these hubs form a distributed but interconnected ecosystem, linking research, breeding, production and commercialisation across the country. India's competitiveness is therefore cluster-driven, with regional specialisation acting as the foundation of national capability.

India's seed ecosystem has been shaped by challenges that define the next phase of global agriculture: **smallholder farming systems, climate variability, productivity gaps and the need for rapid varietal adaptation**. These conditions have enabled India to build a robust foundation in breeding, production and distribution. The next question is whether India's innovation ecosystem can convert these structural advantages into sustained technological leadership. This will depend on advances in biotechnology, molecular breeding, gene editing, digital agriculture and innovation platforms capable of accelerating the journey from discovery to deployment.

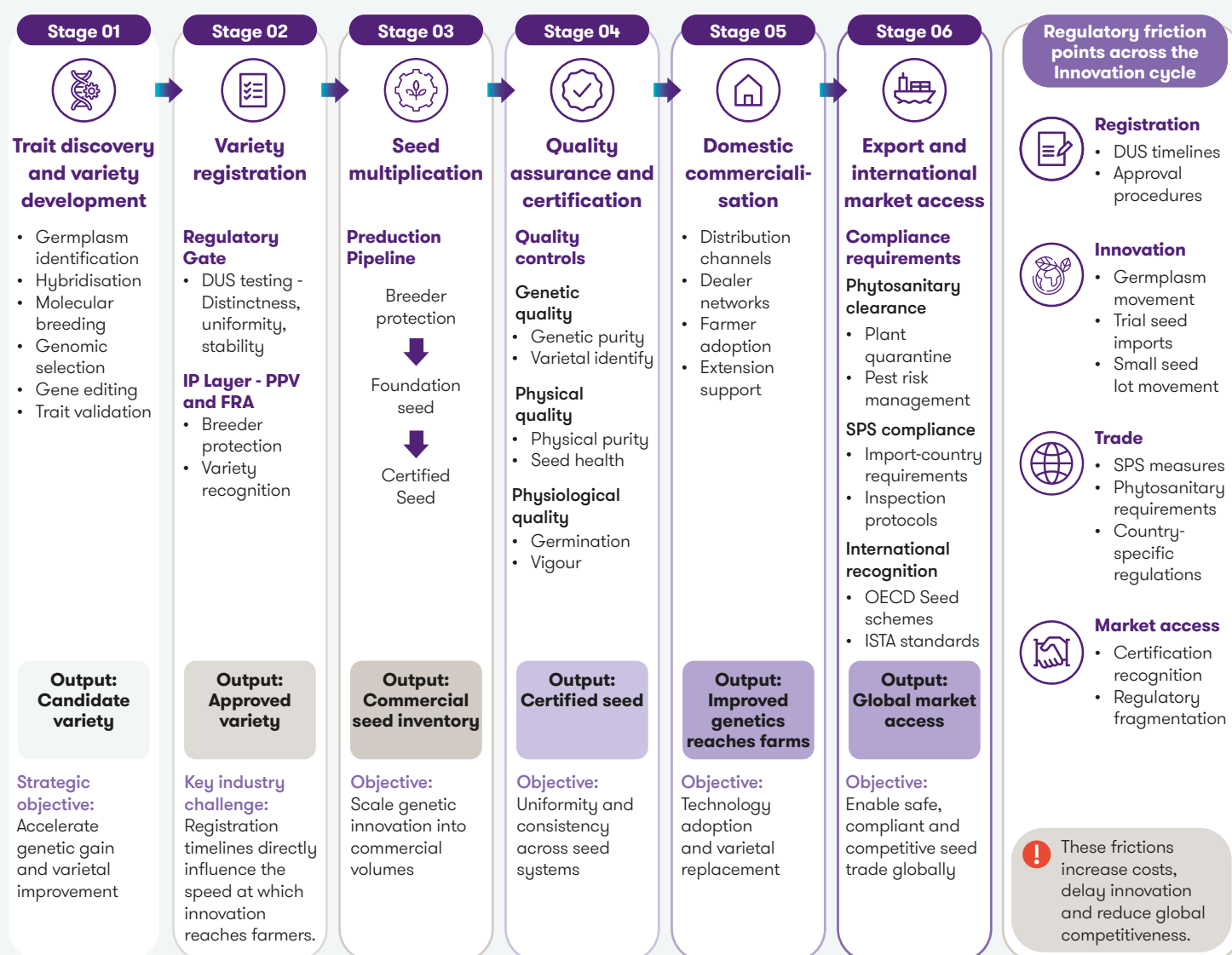


Innovation and technology: The next frontier

The next generation of seed leadership will be determined less by ownership of genetics and more by the ability to continuously shorten the innovation cycle from trait discovery and breeding to commercialisation and farmer adoption. While traditional breeding systems have historically relied on varietal improvement and hybridisation, advances in genomics, gene editing and digital technologies are fundamentally transforming how quickly and precisely improved genetics can be developed, validated and deployed.

Developing a new crop variety has traditionally taken 10-15 years, reflecting extended cycles of selection, testing and regulatory validation. Today, competitive advantage is increasingly defined by the ability to compress this cycle, enabled by technologies that improve both the speed and precision of genetic gain. Innovation is no longer confined to breeding programmes alone; it is reshaping the entire innovation cycle, from discovery to deployment, shifting the industry's focus from developing better varieties to developing them **faster, more precisely and at scale**.

Regulatory journey of a seed



Innovation reaches farmers when all elements work together



Key insight

In the seed industry, competitiveness is determined not only by the ability to develop superior genetics but by the ability to move those genetics efficiently through registration, certification and trade systems. As breeding increasingly global, regulatory efficiency is becoming a strategic component of innovation itself.



2.1 India's R&D ecosystem

India's seed innovation ecosystem is anchored in a strong public research foundation led by ICAR and State Agricultural Universities complemented by a wide network of national and international crop research institutions. These include organisations such as ICRISAT, crop-specific research systems like IRRI (for rice) and other CGIAR-affiliated centres, as well as central and state agricultural universities engaged in varietal development across crops and agro-climatic zones. ICRISAT and partner research institutions have advanced genome sequencing and integrated genomic discoveries into crop improvement programmes across key dryland crops. This has supported the development of high-yielding varieties of chickpea, pigeonpea and groundnut with improved tolerance to biotic and abiotic stresses, alongside enhanced nutritional traits.

On the industry side, institutions such as the National Seed Association of India (NSAI) and global seed companies operating in India contribute to technology diffusion, commercialisation and access to advanced breeding platforms.

Historically, the system has functioned through **technology transfer and licensing mechanisms**, enabling private firms to commercialise publicly developed germplasm while maintaining relatively open access to research outputs. **Public systems have remained central to varietal development in staple crops, while private firms have focused on hybrids, vegetables and higher-value segments.** Global firms typically lead in advanced biotechnology, genomics and digital breeding platforms, while Indian companies play a critical role in localisation, adaptation and large-scale commercialisation.

This model has supported **broad-based innovation across a diverse crop base**, but it is increasingly being challenged by the changing nature of seed R&D. However, it also reflects structural characteristics inherited from India's agricultural system. Similar to the farm sector, the seed industry remains fragmented, with many small and mid-sized firms and limited integration across research, breeding and commercialisation. While this fragmentation supports wide geographical coverage and crop diversity, it hampers scale, slows technology diffusion and limits rapid innovation.

Globally, leading seed companies invest 8–12% of their revenue in R&D, allowing them to continuously enhance breeding platforms and accelerate innovation. In contrast, India's fragmented seed ecosystem limits investment capacity and slows the adoption and spread of new technologies.

India's innovation system is therefore strong in scientific capability and access to germplasm, but still evolving in its ability to scale, integrate and commercialise innovation at speed.

Emerging technologies in seed science for sustainable agriculture

	01 Key technologies 	02 Impact 	03 Applications 
Hybridisation and advanced breeding systems	Hybrid breeding, CMS systems, Restorer technologies, hybrid rice, hybrid mustard, hybrid vegetables	Improves yield potential, varietal replacement and commercialisation of improved genetics	Hybrid crops such as maize, cotton, vegetables and sunflower are among the largest commercial seed segments globally.
Molecular breeding and genomics	Marker-assisted selection (MAS), Marker-assisted backcrossing (MABC), genomic selection, SNP platforms, SSR markers, GWAS	Enables identification of desirable traits before phenotypic expression; improves breeding precision	Widely used for drought tolerance, disease resistance, quality traits and accelerated varietal development
Gene editing and new plant breeding technologies (NPBTs)	CRISPR-Cas9, SDN-1, SDN-2, genome editing, trait engineering	Moves breeding from trait selection towards targeted trait design	CRISPR-edited cowpea developed for synchronised flowering and mechanised harvest; CRISPR rice programmes targeting higher photosynthetic efficiency and resource-use efficiency
Speed breeding	Controlled environment breeding, extended photoperiod systems, accelerated generation advancement	Multiple breeding cycles within a single year	Increasingly integrated with gene editing and molecular breeding platforms
AI, ML and digital breeding	AI/ML, genomic prediction, digital phenotyping, computer vision, high-throughput phenotyping	Shifts breeding from observation-based to prediction-based decision making	AI-enabled seed quality assessment achieving >95% classification accuracy; predictive breeding models reducing field evaluation requirements
Precision agriculture and digital seed production	UAVs, drones, IoT sensors, remote sensing, precision agriculture platforms	Improves seed production efficiency, quality management and traceability	Increasing deployment in high-value vegetable seed production and contract seed production networks
Advanced seed enhancement technologies	Seed priming, seed coating, pelleting, biological treatments, nano-coatings, microbiome-based solutions	Enhances germination, seedling vigour, nutrient delivery and stress tolerance	Nano-enabled coatings allow controlled release of nutrients and crop protection agents; biological coatings improve seed establishment under stress
Blockchain and seed traceability systems	Blockchain, QR verification, digital certification, smart contracts	Improves transparency, authenticity and compliance	PJTSAU-TraceX blockchain-based seed traceability initiative in Telangana
Technology convergence platforms	AI and genomics, IoT and seed production, robotics, fintech, digital compliance systems	Creates integrated innovation ecosystems across the seed value chain	Emerging focus area identified by industry roadmaps and innovation platforms globally

2.2 Biotechnology and gene editing accelerating precision

Biotechnology has transformed breeding from an observational process into a precision-driven science. The first wave of innovation focused on hybridisation and molecular breeding, enabling significant gains in productivity, disease resistance and varietal improvement. Today, approaches such as marker-assisted selection, genomic prediction, and gene editing are widely integrated into breeding pipelines, enabling earlier identification of desirable traits and improving the probability of successful outcomes.

Among these technologies, gene editing is attracting particular attention. CRISPR-based approaches allow targeted modification of traits associated with drought tolerance, disease resistance, nutrient-use efficiency and climate resilience without lengthy breeding cycles associated with conventional approaches. Combined with speed breeding and genomic selection, these tools allow multiple breeding cycles within a year, significantly increasing annual genetic gain.

While gene editing represents the frontier of innovation, the near-term competitive advantage lies in the scaling of proven molecular breeding platforms, which are already delivering measurable efficiency gains across crops.

Innovation in seed systems is increasingly shifting from **trait selection to trait design**, with breeding becoming more targeted, predictable and efficient.

2.3 Digital agriculture and precision accelerating predictive breeding

If biotechnology is improving precision, digital technologies are transforming speed.

AI, ML digital phenotyping, remote sensing, drones and genomic analytics are enabling breeders to:

- Analyse larger populations;
- Predict varietal performance more accurately; and
- Make selection decisions earlier in the breeding cycle.

The primary bottleneck in breeding is no longer data generation, but data interpretation. The ability to combine genomics, environmental data and predictive analytics is **enabling breeding programmes to move from observation-based decision making towards predictive decision making.**

The implications extend beyond breeding into seed production, quality management, traceability and operational efficiency, where precision agriculture technologies are increasingly being integrated across the value chain.

2.4 Strengthening innovation in India through startups and next-generation platforms

The next generation of seed innovation is unlikely to emerge from a single breakthrough technology. Instead, it is increasingly being driven by innovation ecosystems that connect breeding institutions, technology providers, startups, public research organisations and private seed companies.

Startups are filling gaps that traditional breeding organisations were never designed to solve. These include digital phenotyping platforms, seed traceability systems, biological and microbiome-based solutions, AI-enabled breeding analytics and farm intelligence tools that improve decision-making across the seed value chain. At the same time, incubators, innovation clusters and public-private partnerships are expanding access to advanced technologies that would otherwise remain concentrated within large research institutions.

For India, this presents a significant opportunity. The country already possesses a strong research base, diverse agro-climatic testing environments and a large seed production ecosystem. The next next step is in strengthening:

- Technology adoption across breeding programmes
- R&D intensity and integration across public and private systems
- Commercialisation speeds from research to market deployment

The future of seed competitiveness will be determined not only by the quality of genetics, but by the strength of the innovation ecosystems capable of continuously converting scientific advances into farmer-ready solutions.

As climate variability intensifies and resource constraints deepen, innovation will play a critical role not only in improving productivity but also in enabling resilience. The next chapter examines how this innovation capabilities intersect climate challenges and the evolving sustainability imperatives of global agriculture.

A close-up photograph of a pair of weathered, brown hands gently cupping a small, vibrant green seedling. The seedling has several leaves and is growing out of a mound of dark, rich soil. The background is a soft-focus green, suggesting a natural, outdoor setting. The entire image is framed by a thin, white, curved line that follows the shape of the hands and the seedling.

Climate, policy and regulatory drivers of seed systems

Climate change is fundamentally altering the conditions under which agriculture operates. Rising temperatures, erratic rainfall, prolonged droughts, floods and emerging pest infestations are **increasing both yield variability and production risks** across geographies.

Agriculture is now among the most climate-exposed sectors globally, with **extreme heat events alone** capable of reducing agricultural productivity by up to **50% in severe conditions**. In India, even a **1°C increase in temperature can reduce wheat**

yields by 3–10%, highlighting the sensitivity of crop systems to climatic stress.

Under these conditions, climate risk is no longer cyclical, rather, it is structural, directly affecting stability of food systems and farmer incomes. The response to these risks is increasingly shifting towards interventions that can scale rapidly and deliver impact at the farm level.

3.1 Seeds and seed systems for climate resilience

Seeds represent the first and most scalable point of adaptation in agriculture. Unlike infrastructure or agronomic interventions that require significant time and investment, **improved genetics can be rapidly deployed, adopted across farming systems and continuously enhanced through innovation cycles**. As climate risks intensify, climate-resilient seed varieties designed to withstand drought, heat, flooding, salinity and pest pressure are becoming central to productivity, food security and long-term sustainability.

Climate resilience in agriculture increasingly begins at the level of the seed.

This is redefining the role of the seed sector: breeding systems are no longer focused solely on maximising yield, but increasingly on ensuring yield stability under stress. Advances in molecular breeding, genomics and data-driven selection are enabling the development of varieties that are both high yielding and more resilient.

However, resilient genetics alone are not sufficient. Resilience at scale depends on the strength of seed systems, i.e., the interconnected network linking breeding, multiplication, certification, logistics and farmer access. As living biological products, seeds are highly sensitive to production conditions, storage and timely delivery. This makes seed systems inherently complex and vulnerable to climate disruptions and supply chain shocks. At the same time, regulatory and trade barriers can delay the movement of breeding material and commercial seed, slowing the diffusion of improved varieties.

As breeding becomes more global and specialised, seed systems are evolving from distribution channels into strategic enablers of climate adaptation, accelerating varietal replacement and improving access to stress-tolerant crops. In this context, food security depends not only on resilient crops, but on resilient systems capable of delivering those crops efficiently and at scale.



3.2 Climate resilience in action

Global research systems provide clear evidence that genetic innovation can directly translate into climate resilience at the farm level. Large-scale initiatives such as CGIAR-led programmes demonstrate how targeted trait integration can deliver measurable outcomes under stress conditions. For instance, drought-tolerant maize programmes developed by CIMMYT have released more than 200 improved varieties, delivering 25–30% higher yields under drought conditions, thereby significantly reducing production risk.

Similarly, flood-tolerant rice varieties such as Swarna-Sub1 (IRRI) show how embedding submergence tolerance into widely adopted varieties enables cultivation in flood-prone ecosystems without compromising yield potential. In parallel, ICRISAT’s portfolio of dryland crops including sorghum, millet, chickpea and groundnut, focuses on crops inherently suited to heat, drought and erratic rainfall, strengthening resilience in water-stressed geographies.

Field-level deployments further reinforce these outcomes. In drought-prone regions, the adoption of stress-tolerant crops has been shown to increase yields by up to ~55%, highlighting the direct and immediate productivity benefits of resilient genetics under real-world conditions.

The shift towards climate-resilient agriculture is redefining what is bred and how it is delivered. Breeding systems must increasingly balance yield potential with yield stability, while genetic innovation must be matched by faster varietal deployment cycles and stronger last-mile delivery systems. For countries like India, which possess strong agro-climatic diversity and established breeding capabilities, the opportunity lies in translating these strengths into scale and speed of deployment. The defining challenge is therefore no longer limited to developing resilient varieties, but to **ensuring that improved genetics reach farmers quickly, consistently and at scale.**

Program	Climate risk	Solution type	Impact	Strategic insight
DTMA (Maize, CIMMYT)	Drought	Stress-tolerant genetics	+25–30% yield	Reduces downside risk
Swarna-Sub1 (IRRI)	Flooding	Submergence tolerance	Yield retained	Enables farming in high-risk zones
Heat-tolerant wheat	Heat stress	Thermal resilience	Stable grain filling	Protects staple productivity
ICRISAT Millets	Heat/drought	Climate-fit crops	Stable yields	Native resilience advantage
Groundnut (ICRISAT)	Rain variability	Water-use efficient	Yield stability	Supports smallholder systems
Tropical legumes	Multi-stress	Early maturity	Risk reduction	Suitable for variable climates

3.3 Regulatory landscape in the seeds segment

In this context, the effectiveness of climate-resilient seed systems depends not only on innovation, but on the policy, trade and regulatory frameworks that govern their movement and adoption. Seed systems operate at the intersection of biology, innovation and trade, making them among the most highly regulated segments of global agriculture. Unlike most

commodities, seeds are living biological materials capable of transmitting pests, diseases and invasive species across borders, requiring layered oversight through quality standards, certification systems, intellectual property regimes and phytosanitary regulations.

Global seed trade flow (case example tomato seeds)

- 1 Breeding:** climate and technology based location for research and development for new variety development

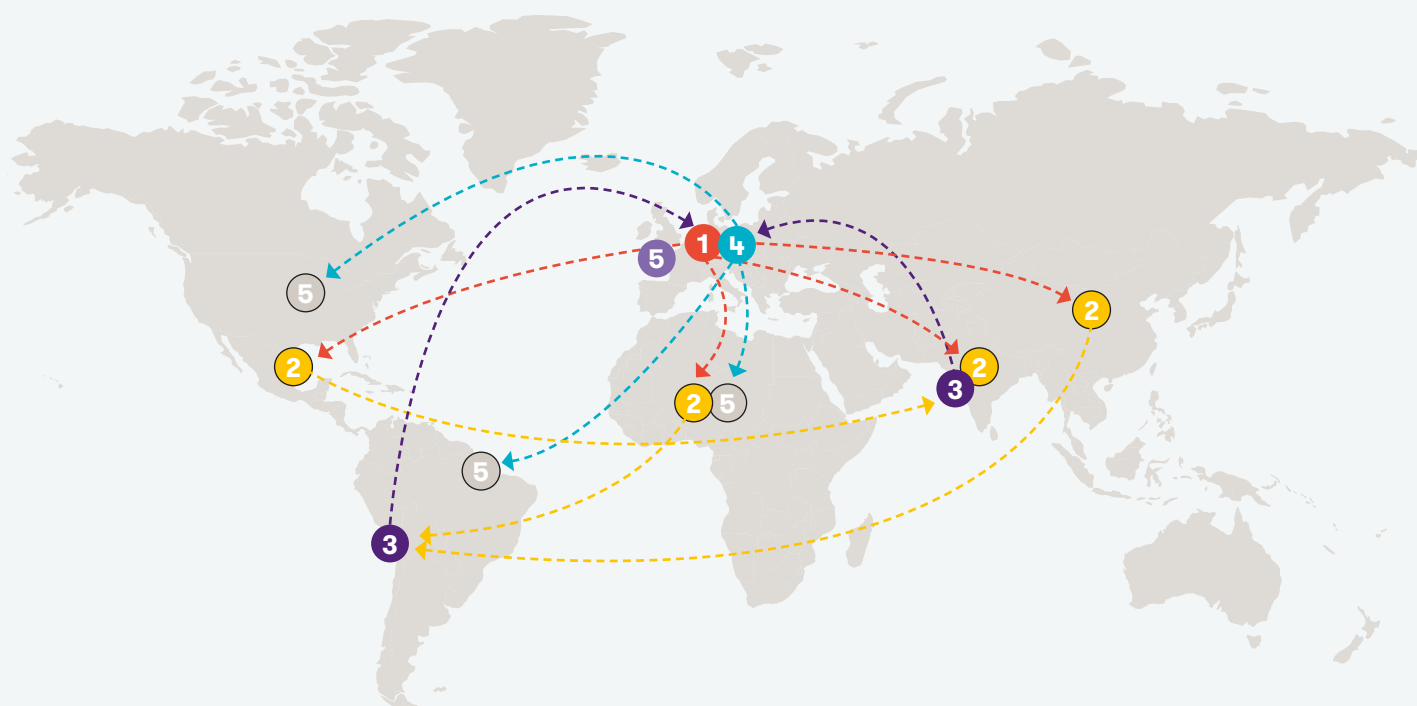


Netherlands, France

- 2 Testing:** Trials of new developed varieties in multi locations and climates for marketability and producibility.



China, India, Nigeria, Mexico



- 3 Producing:** Suitable climate and window for new developed varieties to be produced and sustain the supply for selling countries



India, Chile

- 4 Processing:** Shipment of bulk seed back for cleaning, treating and packing



Netherlands, France

- 5 Sale:** Shipment for commercial sales and distribution



Brazil, United States, France, Nigeria

Disclaimer: Maps are for graphical purposes only. They do not represent a legal survey.

At a global level, this system is anchored in multiple interlinked frameworks. Certification and varietal identity are guided by **OECD Seed Schemes**, quality testing is standardised through **ISTA** protocols, plant variety protection is governed by national or international systems such as **UPOV** or **sui generis frameworks**, while cross-border movement is regulated under the **WTO's Sanitary and Phytosanitary (SPS) Agreement** and the **International Plant Protection Convention (IPPC)**. While these frameworks establish common principles, implementation remains country-specific, resulting in a system that is interdependent but not fully harmonised.

India's regulatory architecture reflects a deliberate attempt to balance four objectives — quality assurance, innovation incentives, farmer rights and market access. This is achieved through a combination of seed quality regulation, intellectual property protection, phytosanitary oversight and biosafety governance.

At the core of this system lies the **Seeds Act framework** (currently undergoing modernisation through the **Draft Seeds Bill**), which governs seed quality, certification, labelling and

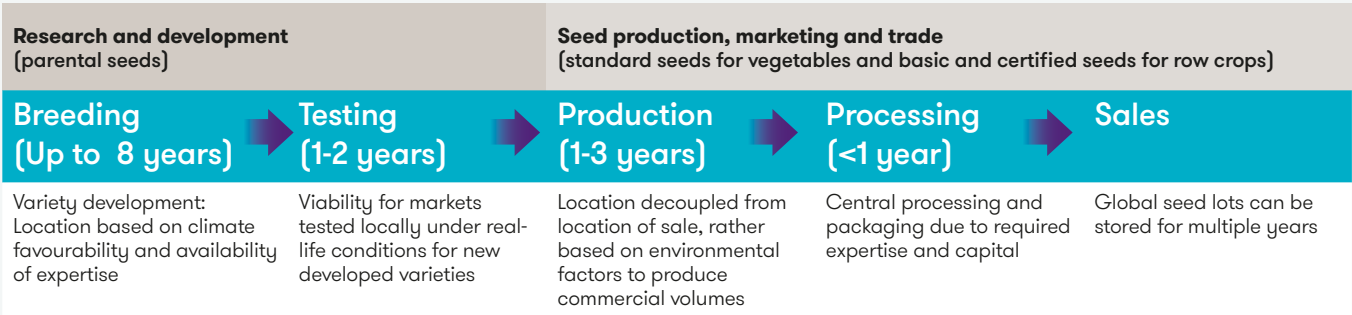
traceability. Alongside this, the **Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act, 2001** serves as India's sui generis intellectual property framework, developed in line with global **TRIPS obligations** while retaining a strong focus on farmer interests.

What distinguishes India's model is its **farmer-inclusive design**. Unlike conventional plant variety protection systems that prioritise breeder exclusivity, PPV&FR explicitly allows farmers to save, use, exchange and replant seeds, while also enabling breeder rights and research access. This creates a hybrid system that supports innovation while maintaining access and participation within the seed ecosystem.

This balance has important implications for innovation pathways. While it supports broad diffusion and farmer adoption, it can also shape private-sector incentives, particularly in high-investment areas such as biotechnology and proprietary traits. As a result, India's regulatory system reflects a careful trade-off between innovation intensity and accessibility, distinguishing it from more protection-driven regimes.

Regulatory frameworks for seeds

Food and Agriculture Organization (FAO)	Convention on Biological Diversity (CBD)	International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA)	Organisation for Economic Co-operation and Development (OECD)
International Union for the Protection of New Varieties of Plants (UPOV)	International Seed Testing Association (ISTA)	International Plant Protection Convention (IPPC)	World Trade Organisation (WTO)



The international regulatory framework for seeds varies according to geographies and to the type of seeds (e.g. OECD Seed Schemes are not implemented for trading of vegetable seeds as they are for agricultural crops).

Layer	Function	Key institutions	Role in seed system
Certification	Varietal identity	OECD	Ensures seed quality and uniformity
Testing	Quality assurance	ISTA	Standardises testing protocols
IP/variety protection	Innovation incentives	UPOV / PPVFR	Protects breeders, enables R&D
Phytosanitary	Biosecurity	IPPC / WTO-SPS	Enables safe international movement



3.4 Market access and trade barriers in the seed industry

In an increasingly innovation-driven seed sector, registration and licensing systems define the pathway from discovery to commercialisation. A new variety creates value only when it successfully transitions through regulatory evaluation, approval and market deployment.

Globally, variety registration systems are anchored in Distinctness, Uniformity and Stability (DUS) criteria, which establish varietal identity and form the basis for registration, certification and plant variety protection. In several jurisdictions, commercialisation may also require agronomic performance evaluations through **Value for Cultivation and Use (VCU) assessments**. Together, these processes ensure that new varieties are identifiable, consistent and capable of delivering expected performance under production conditions. In India, recent regulatory reforms have increasingly focused on strengthening registration rigor, traceability and quality assurance, particularly in response to concerns around spurious or misbranded seeds. However, as breeding technologies reduce development timelines, regulatory processes are becoming a more visible component of the innovation cycle. Delays in testing, approval or market recognition can extend the time required for improved genetics to reach farmers.

Alongside registration, **licensing plays a critical role in enabling innovation diffusion across the seed ecosystem**. Licensing arrangements **govern access to germplasm, parental lines, hybrids and proprietary traits**, linking public research systems, private seed companies and global technology providers. In this sense, licensing is not merely a legal mechanism, but a central channel through which innovation is transmitted, scaled and commercialised. As a result, registration and licensing together function as strategic gatekeepers, determining both the speed of innovation deployment and the distribution of value across the seed value chain.

However, despite increasing globalisation of breeding and seed production, the movement of seed across borders remains highly constrained by regulatory fragmentation. Unlike most traded goods, seeds must comply with phytosanitary regulations, pest-risk assessments, testing protocols and certification requirements, which vary significantly across countries.

SPS measures are designed to protect plant health by preventing the introduction and spread of pests and diseases. While these measures are essential, their implementation often differs across jurisdictions, resulting in country-specific requirements that increase compliance complexity and trade friction. This challenge is particularly acute for the movement of breeder seed, foundation seed and small research consignments, which are critical to global breeding networks. Modern seed development depends on cross-border testing, counter-season nurseries and rapid exchange of genetic material. However, these small, time-sensitive consignments are often subjected to the same regulatory requirements as large commercial shipments, leading to delays, increased costs and operational uncertainty.

Broadly, the number and complexity of non-tariff measures (NTMs), including SPS and technical standards, have increased significantly across major markets, shifting trade barriers away from tariffs towards regulatory and compliance-driven constraints. Even minor errors in documentation or phytosanitary certification can cause shipment delays, rejections or financial losses, underscoring the operational sensitivity of agricultural trade systems.

At the same time, evolving regulatory trends are adding further pressure such as:

- Increasing specific pest-risk requirements across countries
- Declining availability of chemical treatment options for phytosanitary compliance
- Greater reliance on high-sensitivity testing methods (e.g., PCR)
- Long clearance timelines at ports of entry
- Divergent interpretations of harmful organism lists and thresholds

To address these challenges, international frameworks have emerged as critical enablers of seed trade such as:

- **OECD Seed Schemes** facilitate international recognition of varietal identity and certification standards
- **International Seed Testing Association (ISTA)** provides harmonised testing protocols that improve trust and consistency across markets
- **International Plant Protection Convention (IPPC)** and **ISPM 38** establish common approaches for managing phytosanitary risks associated with international seed movement, while plant variety protection systems support continued investment in breeding and innovation.

These frameworks function not merely as compliance mechanisms, but as trade infrastructure. By reducing duplication, improving mutual recognition and facilitating movement of seed across borders, they enable breeding, testing and commercialisation networks to operate more

efficiently on a global scale. However, despite these efforts, full harmonisation remains limited. National regulations continue to diverge in interpretation, implementation and enforcement, creating structural inefficiencies in global seed trade.

Therefore, the policy and regulatory landscape is no longer a background condition for the seed sector, it is a central determinant of innovation, competitiveness and resilience. The countries, which are best positioned in future seed value chains will be the ones capable of balancing innovation, quality assurance, intellectual property protection and seamless market access. For countries like India, the strategic priority lies in balancing domestic objectives of farmer protection, quality assurance and access with the need for increased global alignment and trade facilitation.

The defining challenge is not only to develop better seeds, but to ensure that regulatory systems are able to move those seeds efficiently, reliably and at scale.

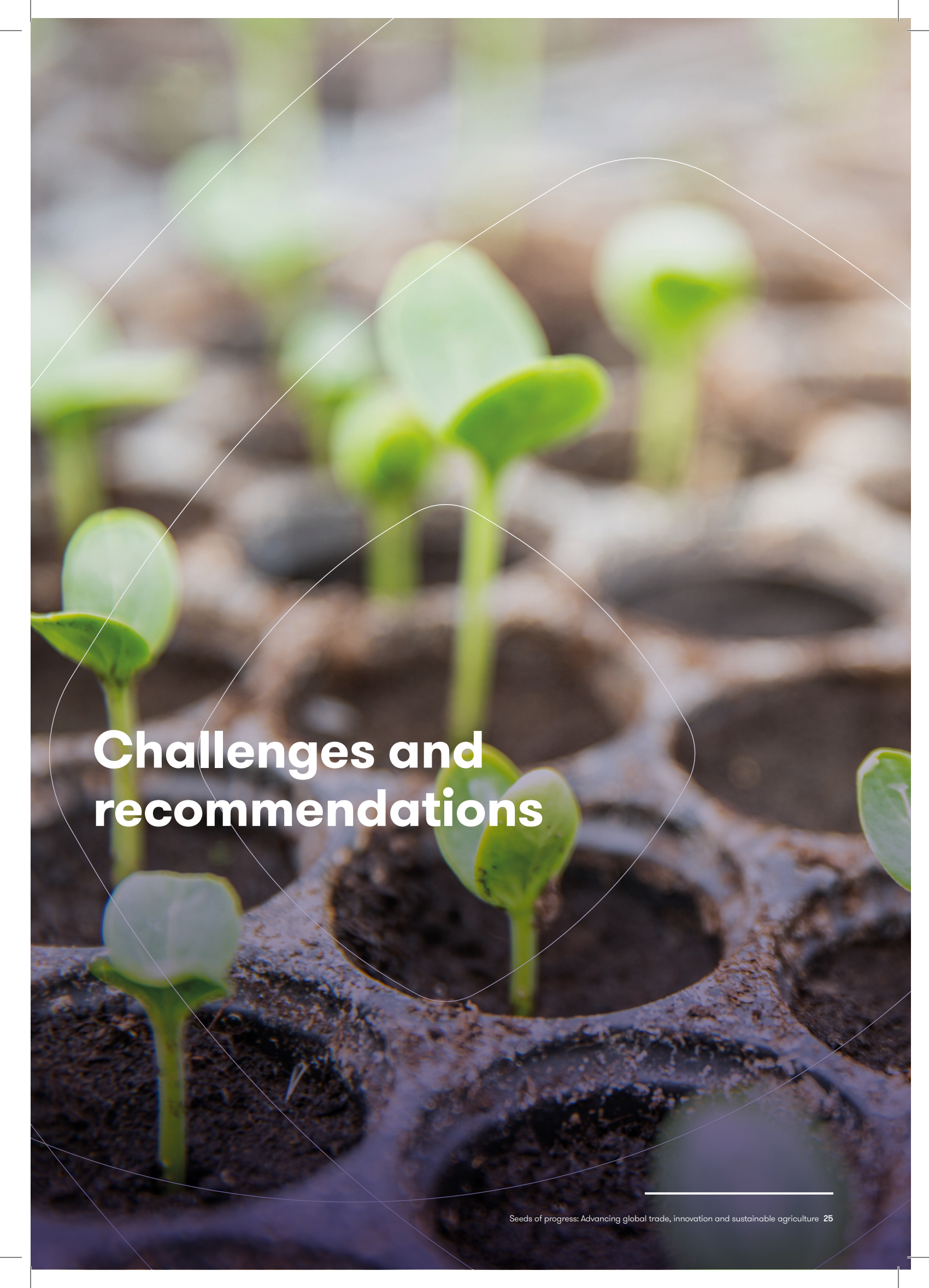
Addressing these constraints requires not only regulatory efficiency, but stronger coordination across research, industry and delivery systems

3.5 Public-private partnerships and ecosystem models

As the seed sector becomes increasingly innovation-driven, translating scientific advances into farmer-level impact depends not only on research capability but on strong collaborative ecosystems. PPPs have emerged as a critical mechanism to bridge this gap, combining public research strength with private-sector capabilities in commercialisation, distribution and investment.

Globally, competitiveness in the seed sector is increasingly shaped by ecosystem strength rather than individual firms. The Netherlands' vegetable seed leadership (Seed Valley-Wageningen), the US' integration of USDA and land-grant universities with private breeding networks, and Brazil's EMBRAPA-led partnerships demonstrate how coordinated actors can convert research into commercial impact and accelerate varietal adoption.

In India, the foundations for such collaboration are well established, with a strong ICAR-led public research base and a dynamic private seed sector, particularly in hybrids and high-value crops. The success of Bt cotton highlights the transformative potential of PPPs in delivering yield gains and reducing input intensity through integrated public-private innovation and farmer adoption pathways. However, the key challenge remains accelerating the transition from innovation to adoption, where commercialisation and delivery often act as bottlenecks. Moving forward, the shift from project-based partnerships to ecosystem-based models — with strong coordination, clear licensing frameworks and deep private-sector integration — will be critical to building scalable, market-oriented seed systems capable of delivering climate-resilient innovations rapidly and at scale.

A close-up photograph of several young green seedlings with two leaves each, growing in a dark brown, textured seedling tray. The seedlings are in various stages of growth, with some showing more developed leaves than others. The background is softly blurred, showing more seedlings and the tray. Overlaid on the image are thin, white, curved lines that create a sense of movement and design.

Challenges and recommendations

4.1 Key industry challenges

India's seed industry has built a strong foundation around food security, productivity improvement and farmer access. However, the next phase of growth will require a transition from **scale-led growth to innovation-led competitiveness**. Global seed-sector priorities are shifting towards advanced breeding, predictable regulation, climate resilience, improved public-private collaboration and rapid delivery of improved varieties to farmers.

Recent industry sentiment reinforces this shift: climate change was ranked as the most challenging issues facing the seed sector by almost 45% of survey respondents, while international trade, seed movement and regulation were also identified as recurring challenges.

Key industry challenges

Challenge area	Current reality	Strategic implication
Innovation delivery gap	Scientific advances exist, but improved varieties do not always reach farmers fast enough or widely enough. Global seed-system discussions continue to highlight low adoption rates of improved crop varieties and limited use of quality seeds and planting materials, even where breeding and seed delivery technologies are available.	India must reduce the distance between research, licensing, multiplication, distribution and farmer adoption. The bottleneck is not only innovation generation, but innovation delivery at scale.
R&D intensity and technology adoption	Leading seed markets are investing in molecular breeding, gene editing, digital breeding and climate-resilient genetics, while India's ecosystem remains fragmented across many firms, institutions and crop priorities. Industry respondents have called for greater public and private investment and stronger plant-science pipelines to unlock innovation.	India needs stronger R&D investment, shared breeding platforms, public-private licensing mechanisms and faster adoption of advanced breeding technologies across firms and public institutions.
Trade and regulatory friction	Seed trade is increasingly shaped by SPS measures, country-specific rules, documentation requirements, certification systems and movement restrictions for small seed lots and breeding material. International seed-sector respondents repeatedly identified trade, seed movement and regulation as current and future constraints.	Expanding exports will require better alignment with global certification, testing and phytosanitary systems, stronger compliance capabilities and regulatory harmonisation with priority export markets.
Climate resilience and biodiversity risk	Climate change, extreme weather, pests and disease pressures are now among the most significant threats to seed-sector performance. Resilient seed systems depend not only on formal commercial channels, but also on agricultural biodiversity, local seed diversity, farmer knowledge and adaptive capacity.	India must scale climate-resilient genetics while also protecting diversity, decentralised access and farmer-managed seed systems, especially in rainfed, dryland, tribal and climate-vulnerable regions.
Commercialisation and PPP gaps	Strong public research capacity is not always matched by efficient commercialisation pathways. Seed-system research shows that improved varieties can remain "stuck" in the delivery pipeline without effective seed systems, market orientation and private-sector engagement.	India needs stronger PPP models, clearer value-sharing and licensing frameworks, and coordinated platforms connecting ICAR, SAUs, CGIAR centres, seed companies, startups, certification bodies and farmer-facing institutions.
Quality, trust and last-mile access	Farmers require timely access to affordable, high-quality and locally suitable seed. The resilient seed systems framework emphasises that seed systems must be equitable, diverse, renewable, healthy and interconnected, with farmers as key actors in seed saving, use and exchange.	The formal seed system must improve quality assurance and delivery while remaining inclusive of local seed networks, community seed systems and farmer-led adaptation mechanisms.



4.2 Strategic India and action agenda

India's strategic opportunity in the seed sector lies at the intersection of three changes — rising demand for improved seeds in emerging agricultural markets, growing value concentration in high-value and climate-resilient seed segments, and the increasing importance of innovation-led seed ecosystems. India already has several enabling strengths such as diverse agro-climatic zones, public and private breeding capabilities, established production clusters, growing scientific talent and increasing global engagement, which position it to move from being a large domestic seed market to a regional seed innovation and supply hub. This direction is also aligned with the objective of positioning India as a global hub for seed innovation, production and trade, while strengthening exports, regulatory harmonisation, climate resilience and public-private partnerships.

The first opportunity is to **build India as a regional seed hub for Asia and Africa. South Asia, Southeast Asia, East Africa and West/Central Africa** share many production challenges that India understands well. These include smallholder farming systems, climate variability, dryland agriculture, productivity gaps and demand for affordable, resilient varieties. This creates a natural opportunity for India to supply seeds suited to similar agro-ecosystems, especially where demand for quality planting material remains high. Global discussions on green seed industry development emphasise the need to make “quality seeds and planting materials of preferred productive, nutritious and resilient crop varieties” available to farmers, particularly in food-insecure regions; a positioning that aligns closely with India's potential role in emerging markets.

The second opportunity is to **move into high-value seed segments, rather than competing only on volume.** India's near-term export potential is strongest in segments where it already has production capability and emerging commercial depth. These include vegetable and horticulture seeds, hybrid seeds, pulses, oilseeds, forage crops and climate-resilient dryland crops. These segments are strategically important because they combine rising demand, higher value realisation and

relevance for climate-vulnerable agricultural systems. The green seed industry framework highlights advanced technologies, conservation and use of plant genetic resources, crop varietal development and seed systems transformation as core priorities, all of which support India's shift towards value-added, innovation-linked seed segments.

The third opportunity is to **build innovation-led growth pathways.** In future, competitiveness will depend on faster breeding cycles, molecular breeding, digital breeding, climate-resilient genetics, stronger licensing systems and more effective commercialisation models. Industry sentiment supports this direction. A 2024 global seed sector survey indicated that new breeding breakthroughs were considered highly likely over the next 10–20 years. Respondents identified increased public and private investment, predictable science-based regulation, strong collaboration and quality seed access as key levers for sector progress. For India, this means strengthening the full pathway from research to market, germplasm access, variety development, registration, licensing, multiplication, distribution and adoption, so that improved genetics do not remain confined to research pipelines. Seed systems research also underlines that released varieties often fail to achieve impact when delivery systems are weak, reinforcing the need to focus on adoption and commercialisation, not only innovation generation.

A fourth, cross-cutting opportunity is to **strengthen resilient and diverse seed systems alongside formal commercial channels.** India's export and innovation strategy should not come at the cost of local adaptation, crop diversity or farmer-responsive seed systems. Resilient seed systems are described as renewable, equitable, diverse, healthy and interconnected, with farmers playing a central role through seed saving, use and exchange. For India, this means pursuing a dual-track model of scaling formal R&D, certification and export-oriented seed systems, while also supporting decentralised seed access, local variety adaptation, community seed networks and farmer-managed systems in rainfed, tribal, dryland and climate-vulnerable regions.

4.3 Policy and industry recommendations

India's seed sector stands at an inflection point. The country has the key attributes required to become a leading seed hub across Asia and Africa. This comprises diverse agro-climatic zones, strong public and private breeding capabilities, established seed production systems, growing scientific talent and increasing integration with global seed value chains. India's strategic focus is to strengthen seed innovation, expand exports, improve regulatory harmonisation, build climate-resilient agriculture, and deepen public-private partnerships.

However, realising this opportunity requires a deliberate shift from a market primarily focused on domestic productivity gains to one increasingly driven by innovation intensity, export competitiveness, resilient seed systems, and ecosystem-based commercialisation. Sentiments in the global seed-sector reinforces this direction. According to a 2024 industry survey, new breeding breakthroughs were considered highly likely over the next 10–20 years. Respondents identified increased public and private investment, predictable science-based regulation, improved collaboration, and quality seed access as key levers for sector progress.

First, India must increase **intensity of innovation**. The next generation of seed competitiveness will depend on rapid breeding cycles, molecular breeding, gene editing, digital breeding, climate-resilient genetics, and strong plant science capacity. While the country has emerged as the world's fifth-largest seed market, research investments remain significantly lower than those of leading seed-producing nations. Increased investment in molecular breeding, biotechnology, digital breeding tools and climate-resilient genetics will be essential if India has to compete in an increasingly innovation-driven global seed economy.

Second, India should adopt a more **export-oriented approach to seed development**. Similar agro-climatic conditions across South Asia, Southeast Asia and Africa provide a natural opportunity for India to serve as a regional breeding, production and seed supply hub. Export-oriented breeding programmes, dedicated vegetable and horticulture seed clusters, and strong international regulatory alignment can help convert this potential into a durable competitive advantage.

Third, **commercialisation** must become a strategic priority. Future growth will depend not only on generating superior genetics, but on reducing the time required for innovation to reach farmers and markets. Strong PPPs, efficient licensing models, startup participation and digital delivery systems will be critical for accelerating adoption and scaling impact.

Fourth, India must **strengthen resilient and diverse seed systems**, not only formal commercial seed channels. Resilient seed systems are defined as renewable, equitable, diverse, healthy and interconnected, rooted in agricultural biodiversity and local seed diversity. For India, this means balancing high-value commercial innovation with farmer-managed seed systems, local variety adaptation, decentralised seed access and community seed networks in climate-vulnerable regions.

Finally, competitiveness will increasingly depend on **ecosystem strength**. PPPs will be central to scaling innovation, linking public science with private sector commercialisation, and delivering new varieties to farmers. Recent India-focused PPP discussions involving TAAS, ICAR, FSII and NSAI emphasise the need for stronger collaboration, equitable benefit-sharing, private-sector investment in agricultural R&D, and clear policy frameworks to scale innovation.

The opportunity ahead is significant. With targeted investments, regulatory modernisation and stronger ecosystem partnerships, India can move beyond being one of the world's largest seed markets to becoming a leading innovation, production and export hub serving the rapidly growing agricultural economies of Asia and Africa.





Strategic pillar	Short-term priorities (1–3 years)	Medium-term priorities (3–7 years)
Innovation and R&D	Accelerate molecular breeding, climate-resilient breeding and digital breeding platforms; strengthen public-private licensing mechanisms; increase investment in priority crops such as oilseeds, pulses and vegetables.	Scale gene editing, speed breeding and next-generation trait development; establish India as a regional breeding and innovation hub serving Asia and Africa.
Regulatory modernisation	Streamline variety registration and approval processes; strengthen traceability, quality assurance and enforcement systems; accelerate digitalisation of certification and compliance processes.	Harmonise testing, certification and phytosanitary systems with major export markets; enable increased mutual recognition of regulatory frameworks and standards.
Export competitiveness	Identify priority export crops and target markets; strengthen OECD-certified seed production systems; promote export-oriented vegetable, forage and horticulture seed clusters.	Develop regional seed hubs serving South Asia, Southeast Asia and Africa; expand India's participation in global seed trade towards the USD 1 billion export aspiration.
PPP and ecosystem development	Strengthen technology licensing platforms and commercialisation pathways for public research outputs; expand public-private breeding collaborations; mobilise ICAR, SAUs, CGIAR centres, seed companies, startups and certification bodies through a coordinated platform.	Build integrated innovation ecosystems linking research institutions, seed companies, startups, regulators, FPOs and international partners; move from project-based PPPs to ecosystem-based innovation models.
Climate and sustainability	Accelerate development of drought-tolerant, pest-resistant and resource-efficient varieties; promote varieties suited for regenerative and sustainable agriculture systems.	Position India as a leading supplier of climate-resilient seed solutions for emerging markets facing similar production challenges.

Conclusion: India's path to global leadership

India's seed sector is at an inflection point. It has the scale, scientific base, agro-climatic diversity, private-sector capability and production ecosystems needed to move from being a large domestic seed market to becoming a global seed innovation and trade hub. The opportunity is especially relevant as global agriculture faces the same challenges India has long managed — smallholder farming, climate variability, productivity gaps and the need for affordable, resilient varieties.

But leadership will not come from scale alone. India must now shift from production-led strength to value-led competitiveness by investing in advanced breeding, strengthening commercialisation pathways, modernizing regulation, expanding export-oriented seed clusters and building integrated public-private ecosystems. The countries that lead the next phase of the seed industry will be those that can develop superior genetics, move them efficiently through regulatory and trade systems, and deliver them reliably to farmers and markets. If India can align science, policy, industry and trade behind this agenda, it can become a trusted global supplier of productive, climate-resilient and affordable seed solutions for emerging agricultural regions.



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