



Beyond the Green Revolution: Unravelling new dynamics of India's agrifood system transformation

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ABSTRACT

For the past six decades, the dominant narrative of India's agrifood system transformation has centred on the Green Revolution, mainly because of its predominant role in making the country self-sufficient in staple cereals. However, this perspective overshadows the equally important transformations that subsequently occurred in horticulture, dairying, poultry, and fisheries, which have contributed significantly to nutritional security, farmers' livelihoods, and agricultural growth. Hence, this paper conceptualises the transformation of agrifood system as a dynamic process that unfolded in three distinct phases: technology-driven cereal intensification (1967–1995), demand-led diversification (1996–2014), and sustainability-led diversification from 2015 onwards. It examines the pace of structural transformation of the agrifood system across these phases and identifies the factors driving the transformation. The findings shows that agricultural growth, which remained at approximately 3% during the first two phases, accelerated to approximately 4.5% in the most recent phase. The composition of growth also changed markedly: cereals dominated the initial phase, horticulture and livestock gained prominence in the second phase, and since 2015, growth has become more broad-based across major commodities, fuelled by technological innovations and growing policy emphasis on sustainability and resilience. Sustaining this growth momentum will require gradual realignment of the Green Revolution-era incentives, particularly input subsidies and price support, with the emerging priorities of resource conservation, climate resilience, and sustainability, while enhancing agricultural productivity, food security, and farmers' income.

Keywords: Agrifood system transformation, Diversification, Policy, Sustainability, Technology

Since the onset of the Green Revolution in the mid-1960s, India's agrifood system has undergone significant transformation. The rapid and widespread adoption of high-yielding rice and wheat varieties, along with the increased use of agrochemicals, supported by investments in irrigation, rural infrastructure, and agricultural research, and the development of institutions for delivery of extension services and credit, along with policy incentives such as input subsidies and Minimum Support Price (MSP), enabled India to achieve self-sufficiency in staple cereals within two decades.

This transformation of the agrifood system did not remain confined to the Green Revolution. In subsequent decades, equally significant transformations occurred in dairy, poultry, fisheries, and horticulture, diversifying the landscape of the agrifood system. Nevertheless, the discourse on India's agrifood system transformation has predominantly highlighted the achievements of the Green Revolution (Gulati *et al.* 2023, Chand and Singh 2024), with little attention to the broader structural transformation of the agrifood system, its underlying drivers, and implications for growth, sustainability, and resilience (Gulati and Juneja

2022, Birthal 2025).

The Green Revolution ensured India's food security, but its unintended consequences on natural resources and the environment soon became apparent. The persistence of incentives, particularly subsidies for fertilisers and electricity for groundwater pumping and the procurement of rice and wheat at MSPs, encouraged the expansion of rice and wheat cultivation at the expense of nutrient-rich crops, especially millets, pulses, and oilseeds, while constraining diversification towards higher-value crops (Negi *et al.* 2020, Birthal *et al.* 2025). This led to overexploitation of aquifers, decline in soil fertility, loss of biodiversity, and environmental pollution in several regions (Chand 1999, Ladha *et al.* 2003, Pingali 2012, Sidhu *et al.* 2019, Birthal *et al.* 2025). Importantly, crops such as rice, wheat, and sugarcane, which receives disproportionately higher policy support, have ceased to contribute to agricultural growth (Chand and Singh 2024).

Recognising the emerging environmental and economic challenges of the cereal-centric development strategy, agricultural policy has gradually broadened its scope. While the policy instruments of the Green Revolution period, notably input subsidies and price support, have remained in place, successive policy initiatives have increasingly emphasised diversification towards high-value agriculture, efficient use of land and water resources, risk management, market integration, value addition, and farmers' income security. These policy changes, coupled with technological

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innovations and expanding market opportunities, have facilitated the development of a more diversified, resilient, and sustainable agrifood system.

This paper, conceptualises India's agrifood system transformation as a dynamic and sequential process shaped by technological innovations, environmental challenges, and market opportunities. The structural break analysis of agricultural Gross Value Added (GVA) shows this transformation progressing through three distinct phases: technology-driven cereal intensification, demand-led diversification, and sustainability-oriented diversification. It examines the structural changes in the agrifood system during each phase, identifies the technological, institutional, market, and policy factors driving these changes, and assesses their implications for the growth and resilience of the agrifood system. Thus, this paper provides a comprehensive understanding of the evolution of India's agrifood system beyond the traditional dichotomy of the Green Revolution and post-Green Revolution or reform and post-reform periods.

Understanding transition in agrifood system

Agri-food system transformation is a dynamic and sequential process driven by the interaction of several demand- and supply-side factors. Rising incomes, urbanisation, and changing consumer preferences lead to changes in food demand patterns towards high-value commodities, signalling producers to diversify their production portfolio from staple cereals to fruits, vegetables, and animal source foods. Technological innovations, public investment in research and infrastructure, market integration, institutional development, and supportive policies facilitate this transition by improving productivity, reducing transaction costs and production risks, and strengthening the value chains (Timmer 2009, Pingali 2015, Deininger *et al.* 2022).

During the 1960s and 1970s, when the overriding policy objective was to achieve food self-sufficiency, technological change, along with investment in infrastructure, institutional development, and policy incentives, enabled the country to attain foodgrain self-sufficiency. As food security concerns receded and economic growth accelerated, urbanisation increased, and dietary preferences diversified, the landscape of the agrifood system progressively shifted towards horticulture, livestock, and fisheries. During the Green Revolution, technological innovations, supported by investments in rural infrastructure, input subsidies, and MSP-based procurement system, led to the emergence of rice-wheat cropping system. However, given its adverse effects on natural resources and environment, policy priorities have progressively broadened to encompass resource-use efficiency, natural-resource conservation, climate resilience, and sustainability.

Drawing on theoretical perspectives and empirical evidence, this paper conceptualises the transformation of India's agrifood system along five interrelated dimensions.

First, technological innovation is the basis of

productivity growth. Developments in the genetics and breeding of crops and animals, aquaculture, mechanisation, biotechnology, and digital innovation consistently push production frontiers. As the agrifood system transforms, research priorities shift from increasing yields to conserving natural resources, enhancing resource-use efficiency, and increasing resilience to climate change.

Second, changes in food preferences and demand provide important signals for structural diversification in agriculture. As incomes rise, urbanisation progresses, and dietary preferences evolve, demand shifts towards high-value foods. These changes in demand patterns encourage producers to reallocate resources towards high-value commodities, which contribute to higher farm incomes and greater employment along the agrifood value chains.

Third, infrastructure development provides a physical foundation for the transformation of the agrifood system. Investments in irrigation, rural roads, electricity, storage, cold chains, logistics, and digital connectivity improve market access, reduce costs of production and marketing, minimise post-harvest losses, and integrate producers into modern value chains, thereby accelerating commercialisation and diversification.

Fourth, institutional developments support technology adoption and market development. Agricultural extension systems, financial institutions, farmer producer organisations (FPOs), cooperatives, contract farming, and regulatory frameworks facilitate technology adoption and market participation by reducing information asymmetries and transaction costs, improving access to inputs, technologies, finance, and markets, and strengthening coordination across the value chain.

Finally, sustainability initiatives address the economic and environmental consequences of agricultural intensification. They shift the development objective from maximising production to sustaining productivity and farm incomes while conserving natural resources through the efficient use of land, water, energy, and other inputs, protecting biodiversity, enhancing climate resilience, and promoting circular bioeconomy practices.

Phases of agrifood system transformation

India's agri-food system has dynamically evolved, aligning with national priorities, expanding market opportunities, and emerging resource constraints and challenges. Traditionally, the literature has studied this evolution in two broad phases: the Green Revolution and the post-Green Revolution or reform and post-reform periods (Pingali 2012, Chand 2017). However, this broad classification overshadows the successive structural changes that have occurred in the agrifood system, as indicated by recent changes in the agricultural landscape (Chand 2019, Gulati and Juneja 2022, BIRTHAL 2025).

The structural break analysis of the time series of agricultural GVA endogenously identifies 1996 and 2014 as statistically significant breakpoints. These breaks, interpreted in conjunction with changes in technology, demand,

markets, policy priorities, and resource constraints, suggest three broad phases of agrifood system transformation: technology-led cereal intensification (1967–1995); demand-led diversification (1996–2014); and sustainability-led diversification (2015 onwards) (Table 1).

Table 1 Structural breaks in agricultural Gross Value Added (GVA) during 1967 to 2025

Variable: Agricultural GVA (at constant 2011–12 prices)			
Optimal breakpoints: 1996, 2014			
AR (0)	du1	du2	(rho - 1)
Coefficients	5882	7728	-0.232
t statistics	10.183	10.423	-2.402
p values	0.000	0.000	-5.490

Note: The Clemente–Montañés–Reyes test endogenously identifies two structural breaks in 1996 (du1) and 2014 (du2). Their significant coefficients confirm the shifts in agricultural GVA at these points. AR(0) indicates no additional autoregressive lags, while (rho–1) is the parameter used to test the unit root hypothesis.

Technology-led cereal intensification (1967–1995): At the time of independence in 1947, India inherited a stagnant agricultural economy characterised by low productivity, chronic food shortages, and heavy reliance on food imports. Therefore, achieving food self-sufficiency was the primary objective of agrifood policy. Initial efforts to increase the production of staple cereals through the Community Development Programmeme (CDP) in 1952, the National Extension Service (NES) in 1953, the Intensive Agricultural District Programmeme (IADP) in 1960–61, and the Intensive Agricultural Area Programmeme (IAAP) in 1964–65 had limited impact. Between 1951–52 and 1964–65, foodgrain production increased by approximately 1.5 mt/annum, from 52 mt to 72 mt. However, this increase was insufficient to keep pace with India's growing food requirements, leaving the country heavily dependent on food imports. During 1965–1967, India imported approximately 10 mt of wheat annually under the PL-480 programmeme.

The beginning of the Green Revolution in the mid-1960s marked a turning point in India's agrifood system transformation. Supported by input subsidies, MSPs, and expanding irrigation, the widespread adoption of high-yielding varieties of rice and wheat, together with increased fertiliser use, led to a rapid increase in foodgrain production. From 1966–67 to 1983–84, foodgrain production increased by an average of about 4.6 mt annually, from 74 mt to 152 mt. This rapid increase enabled India to achieve food self-sufficiency and substantially reduce its dependence on food imports, defying the pessimistic predictions of significant food shortages (Paddock and Paddock 1967).

This initial momentum, generated by technological change and reinforced by supportive policies and investments, continued throughout the first phase (1967–1995). Foodgrain production increased by an average of 4.1 mt annually, far exceeding the annual increases in fruits,

Table 2 Annual increase in production of major agricultural commodities (million tonnes)

	Technology-led cereal intensification (1967–1995)	Demand-led diversification (1996–2014)	Sustainability-oriented diversification (2015–2025)
Foodgrains	4.1	3.9	8.4
Cereals	4.0	3.6	7.8
Pulses	0.1	0.3	0.6
Oilseeds	0.5	0.6	0.9
Cotton	0.2	1.3	-0.6
Fruits and vegetables	2.4	7.7	7.6
Fruits	0.8	2.7	2.6
Vegetables	1.6	5.0	5.0
Milk	1.5	3.9	10.0
Fish	0.2	0.3	0.9
Poultry meat (000' tonnes)	17.9	118.8	211.5
Eggs (billion No.)	0.7	2.6	6.8

Source: Author's estimates based on EPWRF India Time Series available at <https://epwrfits.in/>; Fish estimates based on Handbook on Fisheries Statistics, Government of India (various years); and poultry meat estimates based on Basic Animal Husbandry Statistics, Government of India (various years); FAO (2025).

Note: Fish estimate of the first period is for 1982–1995.

vegetables, milk, meat, eggs, and fish (Table 2). Nevertheless, the unintended consequences of cereal intensification soon became apparent, particularly in Punjab and Haryana, the heartlands of the Green Revolution. The expanding cultivation of rice and wheat gradually evolved into near-monocropping systems. This resulted in biodiversity loss, overexploitation of aquifers, and deterioration of soil and environmental health (Chand 1999, Ladha *et al.* 2003, Rodell *et al.* 2009).

Demand-led diversification (1996–2014): By the mid-1990s, India had consolidated the technological gains of the Green Revolution and achieved food self-sufficiency. At the same time, rising per capita incomes, increasing urbanisation, and changing food preferences shifted consumer demand towards high-value foods, such as fruits, vegetables, milk, meat, eggs, and fish. The economic reforms initiated in 1991, although not directly focused on agriculture, gradually created a more market-oriented economic environment through trade liberalisation, greater private sector participation, and stronger integration between domestic and global markets. Together, these changes created new opportunities for agricultural diversification and commercialisation, marking a gradual transition from technology-led cereal intensification to demand-led diversification (Rao *et al.* 2006, Pingali 2012).

Climate change has emerged as an increasingly pronounced threat to agricultural production, and the environmental consequences of decades of cereal-centric intensification have become more evident. The severe droughts of 2002–03 and 2009–10 led to a significant reduction in agricultural production (World Bank 2013). These factors have reinforced the significant transformation of the agrifood system.

Cereal production continued to rise, but its growth moderated despite the persistent Green Revolution-era policy incentives. The production of fruits, vegetables, milk, meat, eggs, and fish increased rapidly. For example, horticulture production increased by approximately 7.7 mt annually, which is more than three times the annual increase in the preceding phase. Milk production increased by approximately 4 mt annually. Fish production steadily expanded. Poultry emerged as one of the fastest-growing segments. These trends broadened the sources of agricultural growth, from the earlier dominance of cereal-based technological change to greater diversification into high-value agriculture, increasingly shaped by changing demand and market opportunities (BIRTHAL *et al.* 2014).

Sustainability-oriented diversification (2015 onwards): India's agrifood system entered a new phase of transformation in 2015. During this phase, diversification remained an important source of agricultural growth; however, the growing environmental and resource pressures associated with cereal intensification necessitated broadening the agricultural policy framework. Policy priorities have increasingly extended beyond production growth to encompass the efficient use of land, water, energy, and other inputs; conservation of natural resources; climate resilience; digital innovation; value addition; producer organisations; agricultural infrastructure; and improved access to institutional credit and insurance, reflecting a gradual shift towards a more sustainable and resilient agrifood system.

Horticulture production maintained its growth momentum, and milk production recorded the highest annual increase of 10 mt. Fish and poultry production expanded rapidly. Notably, foodgrain production also experienced an accelerated increase of 8.4 mt annually, primarily due to significant improvements in rice and wheat yields. The annual growth rate of rice yield increased from 1.6% during 1996–2014 to 2.1% during 2015–2024; that of wheat from 1.1% to 2.0%, and maize from 2.7% to 3.4%. Unlike the preceding phase, agricultural growth during this phase resulted from both accelerated growth in cereal yield and the rapid expansion of high-value agriculture, making agricultural growth more broad-based.

However, most Green Revolution-era incentives have continued to favour cereal-centric and resource-intensive rice–wheat system. Therefore, sustaining the recent acceleration in agricultural growth requires realigning these legacy incentives with emerging changes in the landscape of agrifood system, with greater emphasis on resource-use efficiency, environmental sustainability, and climate resilience.

Agricultural growth and resilience

The effects of these structural changes in the agrifood system are clearly reflected in the pace and composition of agricultural growth. Agricultural growth increased only modestly from 2.7% during 1967–1995 to about 3.0% during 1996–2014, but accelerated markedly to 4.5% after 2015 (Table 3). The marginal acceleration in agricultural growth during the second phase was nevertheless accompanied by an important change in the composition of growth, as noted earlier. The significant acceleration in growth in the third phase is particularly notable because it has been more broad-based across agricultural commodities rather than being concentrated in a few crops or subsectors.

This acceleration has been closely associated with improvements in land productivity. Growth in agricultural GVA per hectare closely mirrors overall agricultural growth across the three phases (Table 3), indicating that much of the increase in agricultural output has come from generating greater value from a relatively fixed land base. This relationship has become increasingly important as the scope for expanding the cultivated area has diminished. However, the sources of land productivity growth have changed over time. Initially, productivity increased mainly through technological improvements that raised crop yields, particularly cereals. Subsequently, diversification towards higher-value crops and livestock provided an additional source of productivity growth. Thus, India's agrifood transformation has involved not only sustained increases in land productivity but also a gradual shift from predominantly yield-led productivity growth towards a broader combination of technological change and structural diversification (BIRTHAL and HAZRANA 2019, ICAR 2023).

Table 3 Agricultural and land productivity growth (% per annum)

Period	Agricultural GVA	Agricultural GVA per unit of cropped area
1967–1995	2.71	2.62
1996–2014	2.98	3.05
2015–2025	4.51	4.44

Source: Authors' estimates based on EPWRF India Time Series.

However, the acceleration of agricultural growth only tells part of the transformation story. Equally important is whether higher productivity has been accompanied by greater stability in the face of increasing frequency and intensity of extreme climatic events such as droughts, floods, and heat waves. Fig. 1 examines this dimension by comparing the long-term trends in rice and wheat yields and agricultural GVA per hectare with the variability of their negative cyclical deviations across the three phases. During 1967–1995, technology-led intensification generated sustained increases in rice and wheat yields and land productivity, but these gains were accompanied by relatively pronounced downside fluctuations, indicating that rising productivity did not necessarily translate into

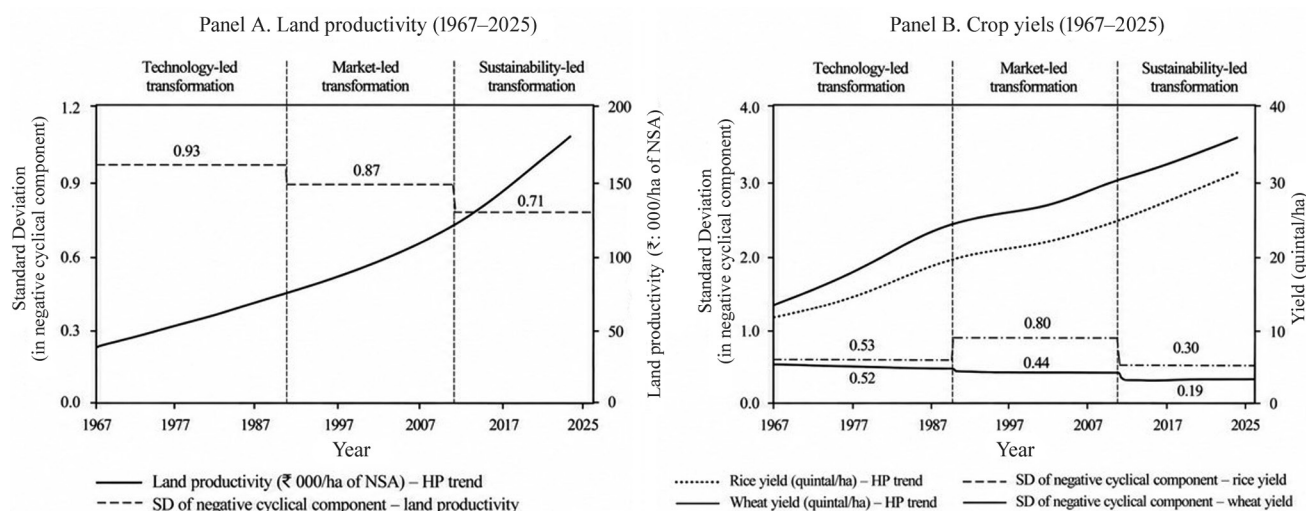


Fig. 1 Land productivity, crop yield and resilience (1967–2025).

Note: Land productivity is measured at constant 2011–12 prices. Land productivity and yields represent trend components estimated using the Hodrick–Prescott (HP) filter with a smoothing parameter of 100. Vertical dashed lines mark the structural break years 1995 and 2014. Horizontal lines are the standard deviation of the negative cyclical component in each period. The negative cyclical components for land productivity in 2016 and for wheat yield in 2015 and 2016 are excluded as extreme observations.

greater stability. During 1996–2014, the relationship began to change. Land productivity continued to increase, while its downside variability declined, suggesting that agricultural growth became more stable at the aggregate level. Wheat exhibited a similar improvement, combining rising yields with a moderate reduction in downside variability. However, rice followed a different trajectory: although yields continued to rise, the variability of negative deviations increased. Thus, the first two phases revealed an uneven relationship between productivity growth and resilience: productivity increased consistently, but the capacity to limit downside fluctuations improved gradually and differed across commodities.

The third phase is distinguished by faster and broader productivity growth, accompanied by a substantial decline in downside fluctuations. This combination of higher productivity and greater stability marks an important qualitative change in India's agricultural growth process, consistent with the increasing emphasis on diversification, resource-use efficiency, risk management, and climate resilience in the evolving agrifood system.

Drivers of agrifood system transformation

The transformation of India's agrifood system has been shaped by the cumulative and mutually reinforcing effects of technological and institutional innovations, changing consumer preferences, infrastructure development, and policy incentives. This section examines their roles in reshaping India's agrifood system.

Changing dietary preferences and structural diversification: Changes in food preferences downstream provide powerful demand signals for changes in the production portfolio upstream. The shift in dietary preference from cereals to high-value foods has been the most important

demand-side force underlying India's agrifood system transformation, driven by rising incomes, urbanisation, demographic changes, and changing lifestyles (Table 4). This transformation is evident in both rural and urban regions. In rural India, the share of cereals in food expenditure declined from approximately 57% in 1972–73 to 11% in 2022–23, while the share of high-value food (milk and milk products, fruits, vegetables, eggs, meat, and fish) increased from approximately 20% to 48%. The corresponding share of cereals in urban India declined from about 37% to 9%, while that of high-value foods increased from about 29% to 47%. Thus, the pronounced rural-urban differences in food consumption that characterised the early stages of agricultural transformation have narrowed substantially.

Research and extension: To respond to evolving food demand, technological innovations are required to increase productivity and facilitate diversification. Investment in agricultural research, including contributions by both the central and the state governments, increased from ₹8.3 billion in 1967 to ₹32.5 billion in 1996 and further to ₹125.4 billion by 2024 at constant 2011–12 prices (Table 5). Investment in agricultural extension also expanded over time, strengthening the dissemination and adoption of improved technologies, production practices, and information among farmers. The economic returns on these investments have been substantial. Kandpal *et al.* (2024) estimated that every rupee invested in agricultural research generates a return of ₹13.85, whereas every rupee invested in agricultural extension yields ₹7.40. Research priorities have evolved with changing production, markets, and environmental conditions. During the Green Revolution, research focused largely on increasing cereal production through improved varieties and input management. From the mid-1990s, it

Table 4 Structural changes in household food expenditure

Year	Food expenditure (% total expenditure)		Cereals & substitutes (% food expenditure)		High-value foods (% food expenditure)	
	Urban	Rural	Urban	Rural	Urban	Rural
1972–73	64.5	72.9	37.0	57.0	29.0	20.0
1983	59.1	65.6	33.0	50.0	34.0	25.0
1993–94	54.7	63.2	26.0	39.0	39.0	32.0
2004–05	42.5	55.0	24.0	33.0	41.0	35.0
2011–12	42.6	52.9	15.5	20.4	43.9	42.0
2022–23	39.2	46.4	9.2	10.6	47.0	48.1

Source: Calculated from published reports of NSSO's consumption expenditure surveys, Government of India (various years).

broadened towards horticulture, livestock, fisheries, and natural-resource management, and more recently towards climate resilience, precision agriculture, biotechnology, and digital innovation (Jat *et al.* 2020, ICAR 2023).

The changing pace and orientation of crop breeding provide a particularly clear manifestation of this technological transition. Between 1969 and 2025, 7,206 crop varieties were released, including 3,569 varieties of cereals; 1,259 of pulses; 1,131 of oilseeds; 693 of fibre crops; 308 of fodder crops and 180 of sugarcane. The pace of varietal development accelerated markedly in the recent period: 3,236 varieties were released during 2014–2025, compared with 1,540 during 2003–2014. At the same time, breeding objectives broadened beyond yield enhancement. Of the varieties released during 2014–2025, 2,996 were climate-resilient, including 1,455 of cereals, 446 of pulses, 397 of oilseeds and 392 fibres. In addition, 187 biofortified varieties were released: 155 of cereals, 28 of oilseeds and four of pulses.

Table 5 Output, input, and Total Factor Productivity (TFP) indices

Items	1967	1996	2015	2022
Output index	24	61	106	139
Input index	47	81	102	119
Land index	73	91	100	103
Labour index	61	96	99	110
Capital index	22	42	118	169
Materials index	14	58	109	166
TFP index	52	75	104	117
Agricultural R&D expenditure (₹billion at 2011–12 prices)	8.3	32.5	94.1	125.4
Agricultural extension expenditure (₹billion at 2011–12 prices)	7.6	10.8	27.5	25.6

Source: USDA (2025), Kandpal *et al.* (2024).

Note: Index number base 2011–12=100.

A similar acceleration is evident in horticultural breeding. Since 1969, a total 1,332 horticultural varieties have been released, including 1,075 of vegetables, 90 of fruits, 89 of spices, 39 of plantation crops, 31 of flowers and nine of medicinal and aromatic plants. Of these, 615 varieties were released during 2015–2026, nearly matching the 717 released over the much longer period from 1969 to 2014. The acceleration has been particularly pronounced in fruits and spices, with 71 fruit and 69 spice varieties released during 2015–2026. The release of 17 biofortified horticultural varieties indicates growing emphasis on nutritional and quality attributes.

Taken together, these developments illustrate an important qualitative change in agricultural research. Crop breeding is advancing at a faster pace and is also broadening in scope, focusing more on specific traits. It is shifting from a mainly productivity-focused strategy to one that integrates productivity with climate resilience, resistance to new pests and diseases, and nutritional quality. This re-orientation of research aligns with the broader goals of India's agrifood system transformation.

Capital formation and rural infrastructure: Technology alone cannot drive growth; it requires support in terms of investments and financing for productive assets and infrastructure. Table 6 shows the trends in investment (gross capital formation) and institutional credit. Gross capital formation increased from ₹427 billion in 1967 to ₹1,106 billion in 1996 and further to ₹4,908 billion by 2024. Notably, private investment accounted for a major share. Institutional credit increased even faster, especially after the mid-1990s, enabling farmers to adopt improved technologies and invest in irrigation, farm machinery and livestock.

Infrastructure plays a crucial role in transforming the agrifood system. Expanding rural roads, markets, storage, and support services encourages the adoption of modern technologies, diversification, and commercialisation. Since the late 1960s, road length has increased eightfold, with the share of rural roads rising from 38% to 69% (Table 7). Notably, investments in rural roads have been shown to deliver higher returns than other infrastructure investments (Fan *et al.* 2000).

Table 6 Gross capital formation in agriculture (₹billion at 2011–12 prices)

Item	1967	1996	2015	2024
Public sector	110	206	372	641
Private sector	317	900	2,355	4,267
Total	427	1,106	2,727	4,908
Share of private sector (%)	74	81	86	87
Credit outstanding	470	1,393	7,293	16,234

Source: Authors' estimates based on data from Agricultural Statistics at a Glance, Government of India (various years); RBI (2025).

Note: Credit estimates in the first column are for 1972.

Significant advances in animal breeding and veterinary services (Table 7), have increased livestock productivity and reduced production risks. BIRTHAL *et al.* (2019) showed that livestock production responds more strongly to improvements in infrastructure than to changes in output and input prices, underscoring the importance of sustained public investment in breeding, animal health, and support services for productivity growth and sectoral transformation.

It is important to note that this transition towards diversification and efficiency-led growth is not due to any single factor; rather, it reflects the interaction of technological progress, capital formation, infrastructure, and institutional credit (Fuglie 2018, Jaiswal and Singh 2024). Together, these factors have reshaped the sources of agricultural growth, moving Indian agriculture beyond input intensification

towards a more diversified, technology-driven, and resource-efficient growth trajectory.

Markets and institutions: Markets and institutions are key drivers of diversification and commercialisation (Timmer 2009, Reardon *et al.* 2012). The rising demand for high-value foods creates opportunities for diversification, while better market connectivity enables farmers to respond to these opportunities (Reardon *et al.* 2012). Institutions such as cooperatives, FPOs, and contract farming facilitate this response by reducing transaction costs, improving access to inputs, credit, information, and technology, and strengthening farmers' bargaining power (BIRTHAL *et al.* 2005, Barrett *et al.* 2012, Pingali *et al.* 2019). Thus, markets create incentives for transformation, whereas institutions determine farmers' abilities to access and benefit from these opportunities.

Table 8 reveals the development of physical regulated markets [includes principal market yards and submarket yards functioning under the State Agricultural Produce Market Committee (APMC) legislation] vis-à-vis the expansion of agricultural output. The number of regulated markets expanded rapidly from 2,145 in 1970–71 to 6,640 by 1990–91, reducing the geographical area served per market from 1,532 km² to 495 km². This expansion was broadly consistent with the requirements of the technology-led phase, when increasing cereal production and marketed surpluses required an expanded network. However, after the 1990s, the expansion of the regulated market network virtually stalled, and consequently, the geographical area served per market remained broadly unchanged at approximately 460 km², far above the benchmark of approximately 80 km² recommended by the National Commission on Agriculture (Government of India 1976) and subsequently reiterated by the National Commission on Farmers (Government of India 2006).

At the same time, the economic volume served by this largely static market network has expanded sharply. The gross value of agricultural output per regulated market increased from ₹1,352 million in 1990–91 to ₹3,549 million in 2023–24. This is important because agricultural production has diversified towards more perishable and high-value commodities, requiring efficient aggregation, storage, transport, and marketing. However, the physical market network has not expanded commensurately, increasing the volume and complexity of the output potentially handled by each market.

The growing mismatch between an expanding and diversifying production system and a relatively static physical market network necessitated alternative marketing channels and stronger market integration. The Model APMC Act, 2003, was a significant step in this direction. It provided a framework for contract farming and private sector involvement. This was followed by the electronic National Agricultural Marketing (e-NAM) initiative in 2016 to spatially integrate agricultural markets for better price discovery, transparency in transactions, lower transaction costs, and expanded market access. By March 2026, the e-NAM platform had successfully integrated 1,656 mandis,

Table 7 Trends in rural infrastructure

(a) Roads				
Indicator	1967	1996	2015	2025
Total roads length ('000 km)	759	2,851	5,472	6,345
Road density (All-India, km/'00 km ²)	23	87	166	193
Share of rural in total roads (%)	38%	57%	61%	69%
(b) Veterinary infrastructure				
Indicator	1996	2004	2014	2024
Veterinary hospitals/ polyclinics (Nos.)	7,415	8,720	11,101	13,173
Veterinary dispensaries (Nos.)	14,573	17,820	22,745	30,184
Artificial insemination (AI) centres (Nos.)	23,682	25,433	27,050	24,532
AI performed ('000s)	18,185	23,835	58,532	1,07,562

Source: Authors' estimates based on EPWRF India Time Series.

Table 8 Trend in regulated markets and Gross Value of Agricultural Output (GVO)

Year	Regulated markets (Nos.)	Geographical area per market (km ²)	GVO per market (₹million, constant 2011–12 prices)
1970–71	2,145	1,532	2,399
1980–81	4,605	714	1,418
1990–91	6,640	495	1,352
2000–01	7,161	459	1,626
2010–11	7,190	457	2,201
2023–24	7,085	464	3,549

Source: Directorate of Marketing and Inspection, Government of India (various years) and Agricultural Statistics at a Glance, Government of India (various years).

demonstrating its extensive reach and effectiveness. In parallel, the promotion of FPOs has strengthened farmers' collective participation in markets by enabling the aggregation of produce and inputs, reducing transaction costs, enhancing bargaining power, and improving access to finance, technology, and organised value chains (NAAS 2026).

The most successful institutional innovation in India's agricultural transformation is the dairy cooperative model. Spearheaded by Operation Flood, launched in 1970, the three-tier cooperative structure organised milk producers into village-level dairy cooperative societies for milk collection and service delivery, linked these societies to district milk unions responsible for procurement, processing, and technical services, and federated the unions at the state level for marketing and distribution. It enabled millions of smallholders and women to participate in dairy value chains while providing regular market access, veterinary and breeding services, feed, and other inputs, and relatively stable cash income. Between 1981 and 2024, the number of dairy cooperative societies increased from 13,284 to 235,877, while annual milk procurement rose from approximately 0.95 mt to 24.2 mt (Table 9). Thus, cooperative procurement increased from approximately 3% of the national milk production in 1981 to approximately 10% in 2024–25. This institutional development strengthened smallholders' access to assured markets and facilitated their integration into a rapidly expanding dairy value chain.

Policy transition

India's agricultural policy has progressively broadened beyond the Green Revolution-era production incentives to encompass diversification, natural resource conservation, risk management, market integration, and farmers' income security. Particularly since the mid-2010s, this broadening has signalled a gradual shift from a predominantly production-oriented approach to an agrifood system perspective that increasingly integrates productivity with sustainability and resilience.

Table 9 Progress of dairy cooperatives

Indicator	1981	1991	2001	2015	2024
Dairy cooperative societies (Nos.)	13,284	63,415	96,206	165,835	235,877
Societies per 1,000 members (Nos.)	8	8	9	11	14
Annual milk procurement (mt)	0.94	3.54	6.02	13.85	24.16
Milk procurement as % of national milk production	2.7	6.5	7.5	9.5	10.1

Source: Authors' estimates based on NDDB (2016, 2024).

Sustainable management of water, soil, and energy: The growing pressure on natural resources has progressively brought resource-use efficiency, conservation, and regenerative agricultural practices into the agricultural policy agenda. The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY 2015) promotes efficient water use, particularly through the expansion of micro-irrigation under its Per Drop More Crop (PDMC) component. Since 2015–16, approximately 9.7 mha have been brought under micro-irrigation by March 2025. The Soil Health Card Scheme (2015) institutionalises soil testing for the balanced application of nutrients. The National Mission on Natural Farming (NMNF 2024) complements these efforts. GOBARDHAN (2018) and Bio-Resource Centers promote a circular bioeconomy recycling agricultural and livestock waste into bio-inputs, organic manure, and renewable energy. Natural-resource conservation is also supported through the Viksit Bharat-Guarantee for Rozgar and Aajeevika Mission (Gramin) (VB-G RAM G 2026), formerly the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS 2005). Moreover, approximately 17 mha of degraded agricultural land, particularly in rainfed regions, have been restored or brought under improved management through research-led interventions. In addition, the National Innovations in Climate Resilient Agriculture (NICRA), launched by ICAR in 2011, has strengthened research, technology demonstration, and capacity building for climate-resilient agriculture by promoting location-specific practices for crops, livestock, fisheries, soil and water management across the country.

The policy framework has also increasingly addressed agriculture's energy footprint. Under the Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan (PM-KUSUM, 2019), about 1.17 million standalone solar agricultural pumps were installed, and approximately 1.60 million grid-connected pumps were solarised by July 2026.

Diversification and high-value agriculture: Agricultural policy has increasingly encouraged crop diversification towards horticulture in response to changing consumer demand, nutritional needs, and opportunities to raise farm incomes. The Mission for Integrated Development of

Horticulture (MIDH) supports quality planting material, protected cultivation, productivity enhancement, post-harvest management, and value-chain development. It is complemented by the Clean Plant Programme (2024), which promotes disease-free, high-quality planting material, and the Agriculture Infrastructure Fund (AIF 2020), which facilitates investment in post-harvest infrastructure, including warehouses, cold storage, pack houses, sorting and grading facilities, and primary processing, thereby helping reduce post-harvest losses and strengthen horticultural value chains.

Dairy and animal husbandry: Livestock policy has progressively broadened to address constraints relating to breeding, feed and fodder, animal health, entrepreneurship, and value-chain development. The Rashtriya Gokul Mission (2014) has strengthened bovine genetic improvement, while the National Livestock Mission (2014–15) supports breed development, feed and fodder, and entrepreneurship. Animal health coverage has expanded through the National Animal Disease Control Programme (2019) and the Livestock Health and Disease Control Programme, with increased emphasis on vaccination and control of major diseases, including foot-and-mouth disease (FMD), brucellosis, peste des petits ruminants (PPR), lumpy skin disease, and classical swine fever (CSF). The One Health approach recognises the interdependence of animal, human, and environmental health.

Dairy cooperatives and producer companies have strengthened aggregation, processing, and market access. The Animal Husbandry Infrastructure Development Fund (AHIDF, 2020) has complemented these institutional arrangements by promoting investment in dairy and meat processing, feed plants, and related value-chain infrastructure. Together, these initiatives have strengthened the foundations for the commercialisation of livestock production and expanded opportunities for value addition and exports.

Fisheries and aquaculture: Fisheries policy has progressively shifted from increasing fish production to the integrated development of fisheries and aquaculture value chains. Building on the Blue Revolution (2015–16), Pradhan Mantri Matsya Sampada Yojana (PMMSY 2020) has strengthened productivity, aquatic health, infrastructure, cold chains, processing, and marketing. Complementary initiatives, including the Pradhan Mantri Matsya Kisan Samridhi Sah-Yojana (PM-MKSSY 2024), have sought to improve formalisation, access to finance, and value-chain efficiency. Policy has also encouraged shrimp farming in non-traditional and inland saline areas, deep-sea fishing, and modernisation of fishing vessels, while improvements in quality, traceability, processing, and cold-chain infrastructure have expanded export opportunities, particularly for shrimp and other high-value seafood.

Markets, processing, and value chain: Production efforts have been supported by market integration, collective action, post-harvest infrastructure, and value addition. The e-NAM (2016) has expanded market access and price discovery. The

formation of 10,000 FPOs has strengthened smallholders' collective capacity for input procurement, aggregation, access to finance and technology, primary processing, and marketing. The Agriculture Infrastructure Fund (AIF 2020) supports investment in post-harvest and community farming infrastructure, and the Pradhan Mantri Kisan SAMPADA Yojana (2017) promotes food-processing infrastructure, cold chains, and agro-processing clusters. The PM Formalisation of Micro Food Processing Enterprises (PMFME 2020) further supports microenterprises and the One District, One Product approach. Together, these initiatives foster integrated farm-to-market value chains, enabling farmers to capture a greater share of the value of their produce.

Digital innovation, and technology-enabled services: Digitalisation has emerged as a cross-cutting driver of agrifood system transformation, facilitating market transactions, direct benefit transfers, access to credit and insurance, crop monitoring, weather information, extension, and farmer advisory services. The Digital Agriculture Mission (2024) seeks to develop digital public infrastructure for agriculture, with AgriStack integrating farmer identities, land records, and crop information to improve service delivery and programme targeting. Kisan Sarathi (2021) facilitates two-way interaction between farmers and agricultural experts, whereas the National Pest Surveillance System (NPSS 2024) uses digital and AI-based tools for pest surveillance, identification, and timely crop protection advisories. Bharat-VISTAAR (Virtually Integrated System to Access Agricultural Resources) (2026) further strengthens this digital architecture through an AI-enabled multilingual platform for context-specific agricultural advisories. Together with remote sensing, geospatial technologies, and digital decision-support systems, these initiatives are contributing to an increasingly integrated digital ecosystem linking farmers with knowledge, public programmes, markets, finance, insurance, and advisory services.

Agricultural credit, insurance, and income security: Policies have increasingly strengthened farmers' capacity to invest and manage production and income risks. The Kisan Credit Card (KCC 1998) has expanded access to institutional credit and was subsequently extended to livestock farmers and fishers, with approximately 77 million operative KCCs by March 2025. Reflecting the wider expansion of institutional finance, agricultural credit disbursement increased from approximately ₹8,450 billion in 2014–15 to over ₹28,000 billion in 2024–25. The Pradhan Mantri Fasal Bima Yojana (PMFBY, 2016) provides protection against crop losses, with cumulative claims of approximately ₹1,830 billion paid by June 2025. PM-KISAN (2019) further strengthened income security through annual direct support of ₹6,000 to eligible farmer families, with cumulative transfers exceeding ₹4,270 billion by March 2026.

Rethinking policies for future agrifood system transformation

The policy challenge for future agrifood system transformation lies in correcting existing policy distortions

and aligning incentives with emerging priorities for diversification, resource-use efficiency, sustainability, and climate resilience while sustaining productivity growth and farm incomes.

From input intensification to resource-use efficiency and self-reliance: Future agricultural growth will hinge on technological innovations and efficient use of resources, given the limited potential for expanding cultivated areas and increasing degradation of natural resources. The Soil Health Card Scheme and Pradhan Mantri Krishi Sinchayee Yojana have established a foundation; however, their success depends on aligning incentives with the conservation of resources. Linking fertiliser subsidies to the nutrient status of soils can ensure balanced nutrient use, reduce fertiliser consumption and subsidy expenditure, and create fiscal space for biofertilisers and sustainable inputs (Jain *et al.* 2026). Additionally, re-designing electricity subsidies to reflect groundwater scarcity, cropping patterns, and farm size can promote more efficient use of water and energy (Srivastava *et al.* 2025).

Furthermore, research should prioritise water- and nutrient-use efficiency, soil health, climate resilience, and resistance to emerging pests and diseases. Genomics, biotechnology, and gene editing should be harnessed to develop high-yielding, resource-efficient, climate-resilient, disease-resistant, and biofortified varieties, with particular emphasis on productivity breakthroughs in pulses and oilseeds. Soil research should increasingly exploit soil and plant microbiomes, beneficial microorganisms, biofertilisers, and biostimulants to improve nutrient cycling, soil fertility, and input-use efficiency. These advances should be integrated with conservation agriculture, precision farming, integrated nutrient and pest management, and digital decision-support systems. More broadly, research should adopt an agriculture–nutrition–health perspective, linking productivity and sustainability with dietary quality, food safety, nutrition, and human health.

From food security to nutrition security: Having achieved cereal self-sufficiency, agriculture must increasingly respond to the rising demand for pulses, edible oils, fruits, vegetables, and animal-source foods, driven by higher incomes, urbanisation, and changing dietary patterns (NITI Aayog 2023). Therefore, policies should promote diversified and sustainable production based on regional agroecological suitability and comparative advantage. Closing persistent yield gaps in pulses and oilseeds through targeted research, improved seed systems, and stronger market incentives can reduce import dependence (Balaji *et al.* 2022, Sharma *et al.* 2023). The development and wider adoption of biofortified crops can enhance the nutritional quality of the food supply and help address micronutrient deficiencies (Yadava *et al.* 2018).

From price support to enabling markets: As production has expanded and diversified, market infrastructure has lagged behind. Policies should strengthen wholesale markets, storage, cold chains, logistics, grading, processing, and digital platforms, while promoting private investment

and farmer collectives. These reforms can reduce transaction costs, improve price discovery, and strengthen farmers' integration into the value chains (Reardon *et al.* 2012, Barrett *et al.* 2012). At the same time, price-support policies should become more compatible with diversification and market signals. Excessive reliance on procurement-based support for rice and wheat reinforces cereal-centric production. A gradual shift towards market-oriented instruments, including well-designed price-deficiency payments, could protect farm incomes while reducing production distortions and allowing farmers greater flexibility in responding to market opportunities (Chand 2019).

From sectoral policies to integrated agrifood systems governance: Agricultural transformation increasingly depends on policies spanning water, energy, climate, trade, food processing, nutrition, and rural development, requiring a whole-of-government approach that strengthens policy coherence, centre–state coordination, and convergence across programmes and investments (FAO 2023). Digital public infrastructure, including AgriStack and the Krishi Decision Support System, can support evidence-based planning, targeting, and monitoring (Government of India 2024). Effective implementation also requires a whole-of-society approach, engaging state and local governments, FPOs, research and extension institutions, the private sector, and civil society. Therefore, the next phase of transformation depends not only on new initiatives but also on greater coherence, convergence, and coordination of existing policies, institutions, and investments (OECD 2018, FAO 2023).

CONCLUSION

This study demonstrates that since 2015, Indian agriculture has entered a more dynamic phase, characterised by faster and more broad-based growth, technological progress, and increasing attention to sustainability and resilience. However, the future transformation faces significant challenges. Persistent productivity gaps in pulses and oilseeds, increasing pressure on land and water resources, climate variability, dependence on critical imported inputs, and changing global trade requirements may constrain future transformation. Therefore, the challenge is not simply to produce more but to produce more efficiently, sustainably, and competitively.

The next generation of agricultural policy should therefore focus on three interconnected priorities: raising productivity and product quality; improving resource-use efficiency; and strengthening resilience to support food self-reliance. This will require gradually realigning existing incentives towards diversified production, efficient use of land, water, nutrients, and energy, climate-resilient technologies, and stronger market linkages. The emphasis should shift from maximising production to producing better-quality and nutritious food more efficiently and sustainably, while responding to changing demand patterns. Such a transition can sustain agricultural growth and farm

incomes while ensuring food and nutrition security and environmental sustainability.

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