Food and Nutrition Security to Mitigate Global Hunger
'Index' apropos India

Edited by

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This e-book is a compilation of resource texts obtained from various subject experts on the Collaborative Online Training Programme on Food and Nutrition Security to Mitigate Global Hunger ‘Index’ apropos India. This e-book is collaboratively edited and published by Dr. Rajendra Prasad Central Agricultural University, Pusa, and the National Institute of Agricultural Extension Management (MANAGE), Hyderabad, to educate agricultural extension professionals, students, researchers, and academicians engaged in agriculture and related fields. The content provided in this e-book is intended solely for educational and knowledge dissemination purposes. The publishers, contributors, authors, and editors disclaim any responsibility for harm or damage to individuals or property resulting from the application of techniques, guidelines, or concepts presented within the e-book. Reproduction or transmission of any part of this publication is strictly prohibited without prior authorization from the publishers.

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Message

Food and nutritional security form the cornerstone of sustainable national development and human well-being. While India has achieved commendable success in agricultural production, emerging as the world's leading producer of milk and the second-largest producer of fruits and vegetables, our position in the Global Hunger Index underscores persistent gaps that demand urgent attention. The paradox of surplus food stocks coexisting with nutritional deficiencies reveals that our challenge lies not merely in production but in distribution efficiency, post-harvest management, and equitable access to nutritious food. To address these gaps, focused efforts are required to enhance the productivity of protein- and fat-rich food sources, particularly pulses and edible oils, through scientific innovation and policy support. Equally vital is community-level awareness about balanced diets, the development of robust producer-to-consumer linkages, and the integration of social, economic, and behavioral dimensions into agricultural planning. As most policies are framed around the family as the primary unit, interventions must be designed to strengthen household-level food and nutrition resilience. Encouraging the cultivation and consumption of biofortified crops—golden Cassava, which has been enhanced to be rich in vitamin A, contributing to improved nutritional outcomes, and traditional crops—such as small millets enriched with essential micronutrients—can significantly contribute to national nutrition goals. However, this requires a parallel shift in consumer preferences and market structures to support demand for these nutritious and climate-resilient crops. The example of Joha rice in the Northeast, which thrives under rainfed conditions, compared to the water-intensive Basmati rice of the North, aptly illustrates the need to consider sustainability alongside productivity. As climate change continues to reshape agricultural landscapes, developing and disseminating multiple stress-tolerant crop varieties becomes imperative. Yet, the long-term solution lies in fostering awareness among both producers and consumers about the ecological and nutritional implications of their choices. This book, "Food and Nutrition Security to Mitigate Global Hunger 'Index' apropos India," is a timely and valuable contribution to this discourse. It brings together insights from researchers, policymakers, and practitioners committed to building a hunger-free and nutritionally secure India. I extend my best wishes to the editors, contributors, and readers, hoping that the knowledge shared within these pages will inspire meaningful actions toward sustainable food systems and healthier communities.

Mayank 27/11/25

Dean, PGCA

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PREFACE

Food and nutrition security remain central to human development and national progress, particularly for a country like India, where agriculture sustains livelihoods for a majority of the population. Despite substantial achievements in agricultural production and self-sufficiency, malnutrition and hunger continue to challenge inclusive growth and social equity. The Global Hunger Index, which reflects the multidimensional aspects of hunger, underlines the urgency for holistic approaches that integrate food availability, access, utilization, and stability. The book "Food and Nutrition Security to Mitigate Global Hunger 'Index' apropos India" brings together scholarly perspectives, empirical insights, and field-based experiences to examine how India can bridge the gap between food production and nutrition security in alignment with the Sustainable Development Goals (SDGs). The chapters in this volume encompass a wide range of themes—from the current status of Indian agriculture and food systems to innovative strategies that enhance dietary diversity, seed replacement rates, and climate resilience. Discussions extend to policy interventions, gender-inclusive nutri-sensitive approaches, and the role of technology such as blockchain in building transparent and efficient food value chains. Together, these contributions underscore that addressing hunger is not merely a question of production, but of systems thinking—where agriculture, health, environment, and social policy converge. This book, collaboratively edited and published by the National Institute of Agricultural Extension Management (MANAGE), Hyderabad, and Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, Bihar, reflects the shared commitment of academia and extension institutions to advance research-based learning for sustainable development. It aims to equip researchers, extension professionals, policymakers, and students with conceptual clarity and actionable insights on strengthening India's food and nutrition ecosystem. By highlighting India's progress and persisting challenges, this volume aspires to contribute to a broader discourse on global food justice. It emphasizes that securing nutrition for all requires synergizing traditional knowledge with scientific innovation, empowering communities, and fostering resilience against climate and economic vulnerabilities. In doing so, it hopes to inspire informed action toward a hunger-free, nutritionally secure, and sustainable future.

Editors

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Opening Remarks and Outcome

The Collaborative National Training Program on "Food and Nutrition Security to Mitigate Global Hunger Index" was organized from 24–26 June 2025 in virtual mode by the Department of Agricultural Extension Education, Dr. Rajendra Prasad Central Agricultural University (RPCAU), Pusa, in collaboration with the National Institute of Agricultural Extension Management (MANAGE), Hyderabad. The programme aimed to equip participants with critical knowledge on food security, nutrition-sensitive interventions, climate-resilient agriculture, and policy frameworks needed to address India's hunger and malnutrition challenges. During the inaugural session, the speakers underscored the urgent need for coordinated action to enhance food availability, accessibility, utilization, and stability. They highlighted India's concerning position in the Global Hunger Index (105th out of 127 countries in 2024), despite strong agricultural output, and emphasized bridging gaps through dietary diversity, women's empowerment, climate-smart agriculture, robust seed systems, and inclusive policy implementation. The opening remarks collectively established the training as a platform to deliberate on strategies for combating hidden hunger, strengthening nutrition-sensitive agriculture, and advancing sustainable development goals. Across the three days, lectures by the eminent experts blended scientific evidence, field experiences, and best practices from across India, offering participants a holistic understanding of food and nutritional security. The training concluded with a strong message: ensuring food and nutritional security requires strengthening household-level awareness, promoting climate-resilient farming, improving public systems like PDS and ICDS, boosting seed quality, diversifying diets, and enhancing transparency in value chains through emerging technologies. The participants expressed that the training enriched their professional outlook and equipped them with actionable insights to promote a more food-secure and nutritionally healthy India. Over the course of the training, the technical sessions provided rich perspectives from experts on topics such as diet diversity, global and national food systems, agroecological models for climate resilience, seed replacement strategies, gender-inclusive nutrition-sensitive agriculture, home gardening, government schemes for reducing hunger, and the use of blockchain for strengthening transparency in food value chains. The lectures combined research evidence, field experiences, successful models, and policy innovations, enabling participants to understand the multidimensional nature of food and nutrition security. The programme fostered interactive discussions and knowledge-sharing, reinforcing that nutrition security requires integrated interventions across agriculture, health, gender, climate adaptation, and technology.

The participants expressed that the training enhanced their understanding of food system challenges and prepared them to contribute more effectively to nutrition-sensitive agricultural development. The programme generated the following outcomes:

- Promote household-level diet diversification through kitchen gardens, biofortified crops, and community nutrition initiatives.
- Strengthen climate-resilient agricultural practices and post-harvest systems to ensure stable and sustainable food supply chains.
- Scale agroecological and climate-resilient farming models to enhance food availability, nutrition, and farmer resilience.
- Expand climate-resilient agriculture demonstrations and localized weather-based advisories at scale across vulnerable districts.
- Integrate gender-transformative approaches into all nutrition and agricultural programmes to enhance household nutritional outcomes.
- Intensify micronutrient interventions, social awareness, and policy convergence to reduce wasting, stunting, and undernourishment.
- Strengthen farmer collectives and market-linkage infrastructures to ensure profitable, sustainable livelihoods in hill agriculture.
- Address child wasting and undernourishment through coordinated community-based nutrition, sanitation, and food access interventions.
- Promote certified seed adoption through awareness, subsidies, digital traceability systems, and farmer–FPO seed production models.
- Promote household and community nutrition gardens with seed kits, training, and convergence with ICDS and SHG networks.
- Integrate blockchain into food value chains to strengthen traceability, reduce leakages, and enhance consumer and farmer trust.

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Current Status of Indian Agriculture & Food Systems Across the Globe

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ABSTRACT

Agriculture remains a cornerstone of livelihoods and food security, even as its relative economic contribution has declined. In India, the sector's share in GDP fell sharply from over 30% in 1991 to around 18% in 2019, while its workforce share reduced significantly, reflecting structural transformation. At the same time, global agriculture employed nearly 857 million people directly, with Asia accounting for 695 million workers in agrifood systems, underscoring the sector's enduring role in employment. The study revealed that in India, 90% of farm households earned less than ₹12,017 per month, with 71% earning below ₹5,000, and only 13% crossing ₹10,000, highlighting severe income disparities despite policy efforts. The Green Revolution of the 1960s and 70s enabled self-sufficiency in wheat and rice, while later diversification expanded into oilseeds, milk, fisheries, and horticulture. Recent initiatives such as e-NAM, AI-based advisories, 10,000 FPOs, and subsidized drone adoption reflect India's move toward digital and climate-smart agriculture. Yet, productivity gaps persist, with cereal yields remaining below global averages and reliance on imports for pulses and edible oils. Situating India's journey within a global context, the paper emphasized that future strategies must focus on balancing productivity, inclusivity, and sustainability while addressing inter-state disparities and environmental challenges.

Keywords: Agricultural income, Employment in agrifood systems, Food system sustainability, Indian agriculture, Structural transformation

1. INTRODUCTION TO FOOD SYSTEMS

According to the United Nations' medium-range projection, by 2050, it is anticipated that there will be 9.3 billion people on the planet (UN, 2011). This demographic growth is likely to be accompanied by a dietary transition, wherein rising affluence leads to a gradual shift from grain-dominated diets towards greater consumption of animal-based foods (Jörissen *et al.,* 2014). This rising demand will place mounting stress on natural resources as well as the

worldwide food availability. According to projections made by the United Nations' Food and Agriculture Organization (FAO, 2009) indicate that agricultural output must expand by 70 percent to sufficiently nourish the world's population by 2050. According to Star and Griesemer (1989), A food system can be understood as a boundary object that unites individuals without necessitating complete agreement. Definitions of food systems typically describe a number of interconnected elements, including production, health, distribution, consumption, and waste (Brock, 2023). Over the last ten years, the food system (FS) discourse has received more attention (Stefanovic *et al.,* 2020). According to the 2030 Agenda set by the United Nations, farming and food production are viewed as integral, cross-cutting factors that connect the 17 Sustainable Development Goals and support progress toward nearly all of them (EEA, 2017; FAO, 2018). Today's food system is regarded as unsustainable, primarily owing to the wide range of negative externalities it generates. Much of this stems from food system activities, which are major drivers of land conversion, biodiversity and habitat loss, alongside environmental pollution affecting air, water and soil (IPBES, 2019; Whitmee *et al.,* 2015). Furthermore, modern food systems contribute roughly 29% of human-induced greenhouse gas emissions, making them a major contributor to climatic variations (Vermeulen *et al.,* 2012). Unsustainable consumption patterns put additional strain on ecosystems (Moscatelli *et al.,* 2016). Socioeconomic inequities are also linked to food systems, often disadvantaging smallholder producers and socially vulnerable groups (Niles *et al.,* 2017). Consequently, they're the standard objective of guaranteeing sufficient food for all remains unmet (Stefanovic *et al.,* 2020). Despite the fact that global food production is adequate to cover dietary demands, around 690 million individuals still face hunger and approximately 11% of humanity experiences inadequate nutrition (FAO *et al.,* 2020; IPBES, 2019). This gap prompted growing recognition of the pressing requirement to reform food systems to enhance their outcomes (Caron *et al.,* 2018). Increasingly, food systems occupy a central position in research and policy discourse, with emphasis on their potential to contribute to shifts toward sustainable growth (Caron *et al.,* 2018; FAO, 2018). While the idea of food systems is longstanding, though its interpretation and depiction have changed over the years. (Stefanovic *et al.,* 2020). Traditionally, food production and distribution systems were viewed as a sequence of activities "from farm to fork," essentially equating them with supply chains or value chains (MacDonald and Reitmeier, 2017; Ruben *et al.,* 2019). This indicated a straightforward, sequential view, where producers are positioned at one extreme and consumers at the opposite end (MacDonald and Reitmeier, 2017; Ruben *et al.,* 2019). Later, the inclusion of waste management and nutrient recycling expanded this linear model into a circular framework, which more effectively

captures the flow of inputs and outputs (Ruben *et al.,* 2019). Recently, acknowledging the complicated dynamics and non-linear relationships in food systems, scholars have adopted visualizations which represent them as interconnected networks (Ruben *et al.,* 2019). This perspective allows farming systems or local food systems to be understood as subsystems nested within the larger global food system (Eakin *et al.,* 2017). Accordingly, one can define a food system as encompassing all processes involved from producing to consuming, the outputs generated by these activities, and factors formed through the interlinkages of biological, geophysical, and human environments along with the feedback linking them (Ericksen *et al.,* 2010). "Food system" refers not only to food production but also to its processing, packaging, distribution, retailing, and eventual consumption, as well as considerations of food security (availability, accessibility, affordability), environmental sustainability, and social well-being (Jörissen *et al.,* 2014). By adopting a food systems approach, researchers and policymakers are able to capture the broad spectrum of social, economic, and environmental effects associated involving food-related processes and to examine the intricate interactions between ecological and human systems (Ericksen, 2009; HLPE, 2014).

2. OUTPUT AND EMPLOYMENT IN AGRICULTURE – INDIA VS REST OF THE WORLD

Economic development is commonly defined as a continuous increase in output per person together with improvements in production capacity and job opportunities (Padder and Mathavan, 2022). Even though the services sector's contribution to GDP has grown significantly over the years, agriculture continues to remain vital to overall economic growth because of its robust demand interconnections with various sectors (Sastry *et al.,* 2003). However, following the onset of economic reforms, both GDP growth and employment in agriculture have witnessed a notable slowdown (De Roy, 2017; Ramaswamy, 2007). During the period from 1960 to 1986, agriculture and related industries did not grow as quickly as India's real domestic product did, making agriculture the leading a means of employing labor both in total numbers and proportionally (Thamarajakshi, 1989). Although GDP growth accelerated after the implementation of new economic reforms, the rate of employment generation declined (Thamarajakshi, 1989).

2.1 Share of Sectoral Output and Employment in India

The sectoral distribution of output in GDP and employment highlights the trends in the Indian economy following economic reforms. Between 1991 and 2006, agriculture's share in the gross

domestic product witnessed a sharp decline, after which it continued to fall gradually up to 2019. In contrast, the contribution of industry to GDP remained almost stagnant following the reforms of 2000, although it rose notably between 2000 and 2008–09 before falling again until 2019. Meanwhile, the services sector consistently expanded its share, surpassing 50 percent of GDP since the initiation of economic liberalization. With respect to occupational opportunities, agriculture experienced a steep reduction in its workforce share over the years (Padder and Mathavan, 2022). Employment in both industry and services has increased slightly, yet from 2011–12 to 2018–19, labour absorption in industry remained stagnant. This indicates that the industrial sector has been unable to generate sufficient jobs for the labour force shifting out of agriculture. Notably, as of 2019, the services sector contributed over 50 percent of GDP, while accounting for only about 30 percent of total employment in India (Padder and Mathavan, 2022).

2.2 Output in Agriculture in the World

Output refers to the total quantity produced, while yield indicates the amount of production generated per input unit typically per unit of land (Steensland and Zeigler, 2020). The agricultural transformation known as the Green Revolution during the 1960s introduced high-yielding new wheat and rice varieties made available to millions of small farmers in India, Mexico and other countries in the developing world, alongside expanded availability of fertilizers, irrigation facilities, and farm machinery. In high-income countries, productivity gains have historically allowed for increased output while simultaneously reducing input use and limiting land expansion. Key innovations driving these gains incorporate modern agricultural technologies, including genetically engineered seeds, new breeding techniques, as well as enhanced crop protection solutions, enhanced breeding and management of farm animals, better livestock nutrition and concern, site-specific crop management, and improved management of soil nutrients. Over the past ten years, nevertheless, productivity growth has slowed even in high-income nations (Steensland and Zeigler, 2020; USDA Economic Research Service, 2018). Countries with low-income levels have mirrored the international trend of growth in Total Factor Productivity (TFP), leading to considerable growth in agricultural production from the 1960s onwards. Yet, since the 1980s, expansion of cultivated land has remained the dominant factor driving output growth. More recently, the role of Total Factor Productivity (TFP) in boosting agricultural production has increased significantly, particularly over the last ten years (USDA Economic Research Service, 2018; Steensland and Zeigler, 2020).

2.3 Employment in Agriculture in the World

The International Labour Organization (ILO) defines employment as encompassing all individuals of employment age who, within a defined brief reference interval (for example a day or a week), were either: (a) engaged in paid employment—whether at work or temporarily absent from it—or (b) self-employed, either actively working or maintaining an enterprise while not at work (Davis *et al.,* 2023). In 2019, approximately 857 million individuals were employed directly in agriculture, with an additional 208 million individuals participating in non-farming agrifood system activities, bringing total AFS employment to around 1.06 billion. The largest share was contributed by Asia, employing approximately 695 million individuals involved in agrifood systems, subsequently by nearly 250 million in Africa (Davis *et al.,* 2023). The study further shows that AFS provided employment for 53 percent of Africa's workforce and about 35% in the Asian region, with the agricultural sector making up the majority in both—48 percent in Africa and 29 percent in Asia. In contrast, in Europe, Oceania, and the Americas, occupational roles are more evenly distributed between agricultural and non-agricultural AFS activities, though the overall contribution of AFS employment is greater in the American region, representing 17.9% compared with the remaining parts of the world (Davis *et al.,* 2023).

3. INCOME FROM INDIAN AGRICULTURE (MONTHLY AVERAGE HOUSEHOLD INCOME)

Given that farm incomes and farmers' welfare remain critical concerns in India, it is essential to study the pattern of distribution of income within farming households (Shukla, 2025). The Situation Assessment of Agricultural Households Survey, undertaken by the NSSO, functioning under MoSPI has encouraged scholars to explore patterns of income inequality within this group (Birthal *et al.,* 2014; Das and Srivastava, 2021; Saini and Kaur, 2022). In terms of monthly farm earnings, around 5 percent of households report either no income or losses, while 90 percent earn below Rs. 12,017. A closer breakdown shows that 27 percent earn less than Rs. 1,000, 44 percent earn under Rs. 2,000, 71 percent fall below Rs. 5,000, and 87 percent make with monthly income less than Rs. 10,000. Only about 13 percent of agricultural households report farm income exceeding Rs. 10,000 monthly. When total household income (farm and non-farm combined) is considered, the distribution still reveals low earnings, with 68 percent of households earning below Rs. 10,000 per month, meaning just 32 percent cross the Rs. 10,000 thresholds. Looking at farm income alone, the share above Rs. 10,000 remains

at only 13 percent, underlining the importance of non-farm activities in supplementing household earnings. Yet, despite this additional income, many households continue to survive on extremely low levels—39 percent report less than Rs. 5,000 monthly, and 14 percent earn under Rs. 2,000. Overall, the averages—Rs. 5,380 in terms of monthly agricultural income and an average overall monthly income of Rs. 10,695—conceal substantial disparities across households (MoSPI, 2019; Shukla, 2025).

3.1 Inter-state analysis of monthly farm income and total income levels of Indian agricultural households

A notable fraction of farm households reports monthly agricultural income under Rs. 1,000, with states including West Bengal, Odisha and Andhra Pradesh showing more than 40 percent of households below this threshold. On the other hand, only a very limited share earns above Rs. 10,000 from farming each month. Earning a monthly income exceeding Rs. 10,000 remains unattainable for the vast majority of households in eight states. This is particularly stark in Jharkhand, Odisha, and West Bengal, where only 1%, 2%, and 3% of households, respectively, achieve this earnings threshold. Looking at total household income (farm and non-farm sources combined), only a small share—ranging between 1 and 9 percent across states—earns less than Rs. 1,000 per month.

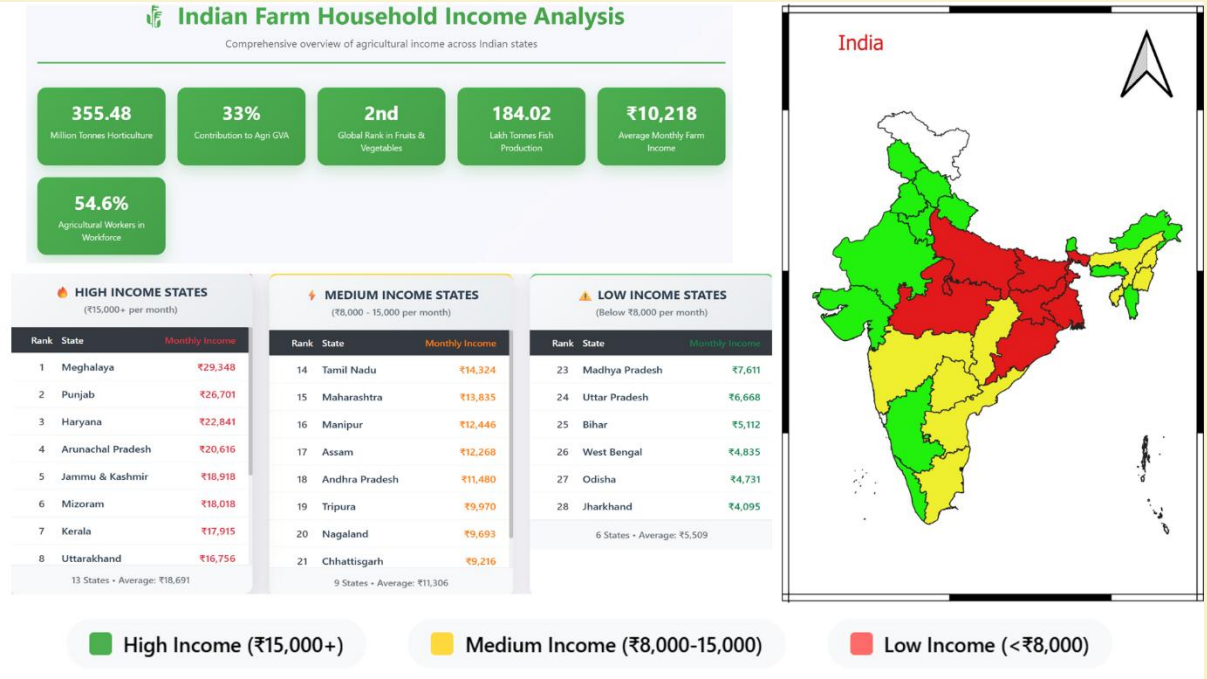


Fig. 1 Farm Household Income across the Indian States (Data Source: NSSO, 2019)

The percentage of households earning above Rs. 10,000 is higher for total income compared to farm income alone, yet large inter-state differences remain. For example, while nearly 74 percent of households in Punjab earn more than Rs. 10,000 monthly, the figure is only about 10 percent in Jharkhand. Despite the contribution of non-farm earnings, an appreciable segment of farming households continues to have very low overall incomes. In states including Jharkhand, Odisha, Uttar Pradesh, Chhattisgarh, West Bengal, Madhya Pradesh, and Bihar, between 75 and 90 percent of households still report monthly incomes below Rs. 10,000 (MoSPI, 2019; Shukla, 2025).

4. EVOLUTION OF INDIAN AGRICULTURE AND POLICIES

4.1 Pre-Independence Agriculture (Before 1947)

Radical land reforms were implemented to uphold democratic principles and address entrenched agrarian inequalities. The zamindari system and intermediary tenures were abolished, tenants were safeguarded against arbitrary eviction and excessive rents, and land ceilings facilitated redistribution of surplus land. Prior to independence, Indian agriculture operated under a feudal structure dominated by landlords, while cultivators remained economically marginalized (Vaidyanathan, 2020). The agricultural landscape was marked by subsistence farming practices, extremely low productivity levels, and frequent famines that devastated rural populations. Indian agriculture remained heavily reliant on monsoon rainfall, with limited irrigation facilities and negligible mechanization, which perpetuated systemic vulnerability across rural regions. Although traditional farming practices were ecologically sound, they proved insufficient to meet the rising food demands of a growing population, resulting in persistent food insecurity and production instability (Srikanthnaik, 2024).

4.2 Post-Independence Phase (1947–1965): Foundation Building

In the aftermath of independence, India undertook sweeping land reforms to dismantle the exploitative colonial agrarian structure. Key measures included the abolition of the zamindari system, enactment of tenancy reforms, and imposition of land ceiling laws all aimed at promoting equitable land ownership. Simultaneously, the government established community development programmes (Cornet *et al.,* 2024), cooperative institutions (Panakaje *et al.,* 2024), and agricultural universities, laying the institutional foundation for long-term agricultural modernization and rural upliftment. During the early post-independence years, India faced acute food shortages that compelled the government to rely heavily on imports through the U.S.-backed PL-480 program (Firstpost, 2025). This dependency underscored the fragility of

domestic agricultural production and emphasized the urgency of attaining food self-sufficiency. These crises catalyzed policy shifts that eventually led to transformative initiatives like the Green Revolution, reshaping India's agrarian landscape in the decades that followed (The Hindu Business Line, 2022).

4.3 Green Revolution (1965–1978): The Productivity Breakthrough

The Green Revolution marked a transformative phase in Indian agriculture during the 1960s and 1970s. It introduced high-yielding variety (HYV) seeds for wheat and rice (Sendhil *et al.,* 2023), supported by intensive use of chemical fertilizers, pesticides, and expanded irrigation systems. This integrated technological package significantly boosted foodgrain production, especially in Punjab, Haryana, and Western Uttar Pradesh, helping India transition from chronic food shortages to self-sufficiency in staple crops (Singh *et al.,* 2022). During the post-Green Revolution period, India's agricultural policy framework underwent significant restructuring. The government introduced the Minimum Support Price (MSP) system to ensure farmers received fair compensation for their produce, particularly wheat and rice, which were procured extensively in states like Punjab and Haryana (Gupta *et al.,* 2021). The Public Distribution System (PDS) was expanded to enhance food access for vulnerable populations, while institutional credit mechanisms were strengthened to enable farmers to adopt modern technologies and inputs (Gowd, 2022). Collectively, these measures shifted India from a food-deficient economy reliant on imports to one that achieved food self-sufficiency by the mid-1970s (Kala, 2022).

4.4 Post-Green Revolution & Diversification (1978–1990): Expanding Horizons

Building on the success of the Green Revolution, India witnessed a strategic expansion of high-yielding technologies beyond Punjab, Haryana, and Western Uttar Pradesh. States like Andhra Pradesh, Tamil Nadu, and Karnataka adopted improved irrigation systems and HYV seeds for crops such as rice, cotton, and sugarcane. Maharashtra and Gujarat saw notable growth in oilseeds and cotton, supported by targeted schemes like the Technology Mission on Oilseeds. In Bihar and West Bengal, rice productivity improved through localized input packages and infrastructure development. This phase reflected a deliberate diversification strategy aimed at reducing import dependence and stabilizing production across multiple agro-climatic zones (MOSPI, 2019). The White Revolution, initiated through Operation Flood in 1970, transformed India from a milk-deficient country into the world's largest milk producer. Spearheaded by Verghese Kurien and the National Dairy Development Board (NDDB) (Gulati & Juneja, 2023),

the program established a nationwide milk grid and empowered rural producers through farmer-owned dairy cooperatives. This initiative not only stabilized milk prices and reduced regional disparities but also enhanced rural incomes and nutrition levels. Parallelly, the Blue Revolution, launched during the Seventh Five-Year Plan, focused on the integrated development of aquaculture and fisheries. It aimed to modernize both inland and marine fisheries, improve infrastructure, and promote sustainable practices (Shenoy & Rajpathak, 2021). The program significantly boosted fish production, enhanced protein availability, and generated employment in coastal and rural regions. Together, these revolutions demonstrated the scalability of the Green Revolution's model across other agricultural sub-sectors, reinforcing the role of technology, cooperative institutions, and targeted policy interventions in achieving sectoral transformation (Pathak *et al.,* 2022).

4.5 Economic Reforms & Consolidation (1991–2015): Market-Oriented Growth

The 1991 economic liberalization marked a turning point in Indian agriculture by opening input and output markets to private sector participation. This shift reduced state monopoly in critical areas such as seeds, fertilizers, agrochemicals, and food processing, fostering competition and technological innovation (Chakraborty, 2024). The entry of private firms led to improved access to quality inputs and diversified marketing channels. Concurrently, farmers began transitioning toward high-value crops notably horticulture, floriculture, spices, and medicinal plants driven by changing domestic consumption patterns and rising export demand (Ayyappan *et al.,* 2007). States like Maharashtra, Tamil Nadu, Karnataka, and Andhra Pradesh emerged as hubs for horticultural expansion, while West Bengal and Kerala saw growth in floriculture and spice cultivation. These trends reflected a broader diversification of the agrarian economy, aligning agriculture with global market dynamics. The post-liberalization phase of Indian agriculture embraced a more integrated development strategy through the implementation of watershed development programmes, micro-irrigation systems, and expanded rural credit schemes (Chokkakula *et al.,* 2021). These interventions acknowledged the critical role of natural resource management, water-use efficiency, and financial inclusion in sustaining long-term agricultural growth. Programmes like the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) and the Micro Irrigation Fund (MIF) under NABARD facilitated widespread adoption of drip and sprinkler irrigation, particularly in water-scarce states such as Andhra Pradesh, Gujarat, Tamil Nadu, and Rajasthan, covering over 22 lakh hectares by 2025 (National Bank for Agriculture and Rural Development, 2024). Simultaneously, rural credit access was enhanced through institutional reforms and targeted subsidies, enabling small and marginal

farmers to invest in climate-resilient technologies and resource-conserving practices (Ministry of Agriculture & Farmers Welfare, 2025).

4.6 Resurgence & Modern Policy Initiatives (2015–Present): Digital and Climate-Smart Agriculture

The current phase of Indian agriculture was defined by the integration of digital platforms and climate-resilient innovations. A key milestone was the launch of the National Agriculture Market (e-NAM) in 2016, a pan-India electronic trading portal that connected over 1,470 regulated APMC mandis across 23 states and 4 union territories. Implemented by the Small Farmers Agribusiness Consortium (SFAC) under the Ministry of Agriculture and Farmers' Welfare, e-NAM streamlined agricultural marketing by enabling real-time price discovery, transparent auctions, and online payments, thereby reducing information asymmetry and transaction costs (Ministry of Agriculture & Farmers Welfare, 2025). This initiative operationalized the vision of "One Nation, One Market", allowing farmers to trade beyond local mandis and access national-level buyers. By harmonizing quality standards and simplifying licensing procedures, e-NAM empowered smallholders to secure better prices and enhanced market access for their produce (Department of Agriculture, Cooperation and Farmers' Welfare, 2017). Digital agriculture initiatives significantly reshaped farm-level decision-making and information dissemination in recent years. AI-based advisory systems, such as ICAR's Agromet Advisory and the Kisan e-Mitra chatbot, provided real-time, hyper-local insights on weather, crop health, and pest surveillance, enabling smallholders to make informed decisions amid rising climate risks (Ministry of Agriculture & Farmers Welfare, 2025). Platforms like VISTAAR and Krishi Saathi further enhanced extension services by integrating AI-powered content delivery in regional languages. The government also prioritized the formation of Farmer Producer Organizations (FPOs) under a Central Sector Scheme, aiming to establish 10,000 FPOs by 2027–28 (Ministry of Cooperation, 2023). These collectives empowered small and marginal farmers by improving access to inputs, credit, and markets. States like Maharashtra, Uttar Pradesh, and Madhya Pradesh led in FPO registrations, with over 44,000 FPOs formed nationwide by 2025. Simultaneously, support for agri-startups and subsidized drone usage accelerated the adoption of precision farming. Initiatives like the Kisan Drone Scheme provided 50–100% subsidies to FPOs and Custom Hiring Centers for drone procurement (Ministry of Agriculture & Farmers Welfare, 2025). These drones facilitated aerial spraying, crop monitoring, and damage assessment, reducing input costs and enhancing productivity.

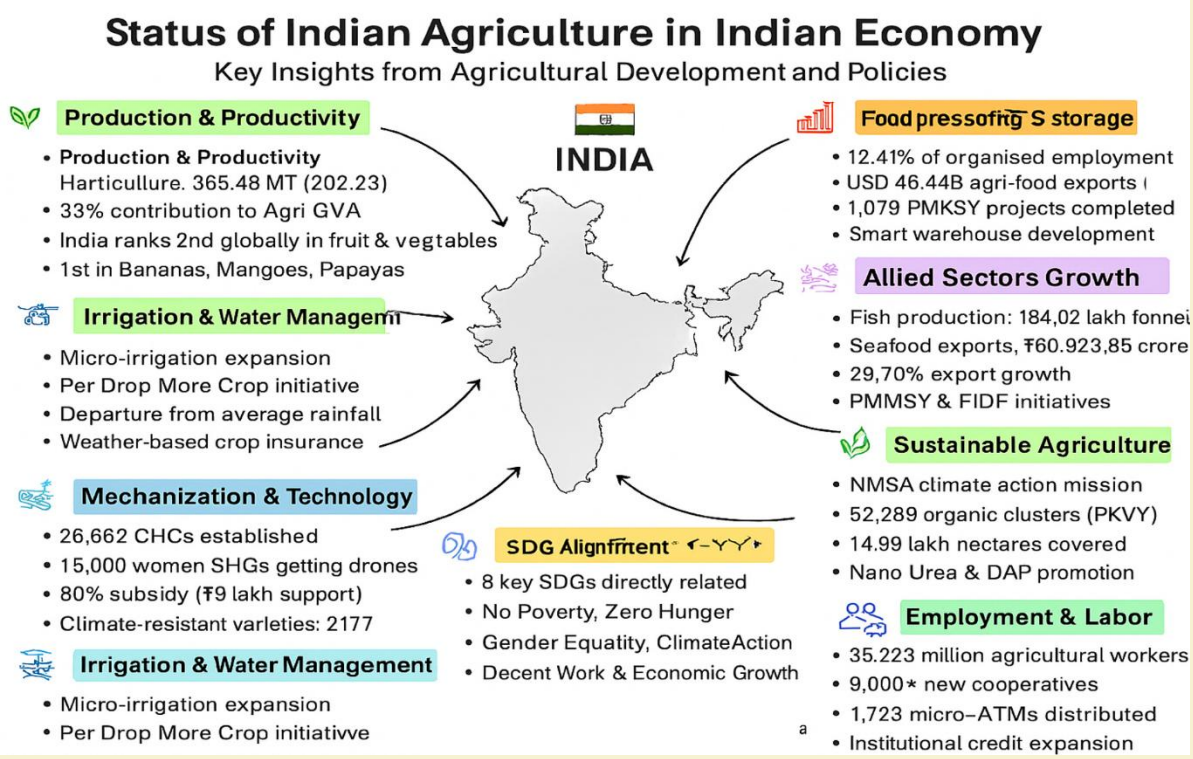
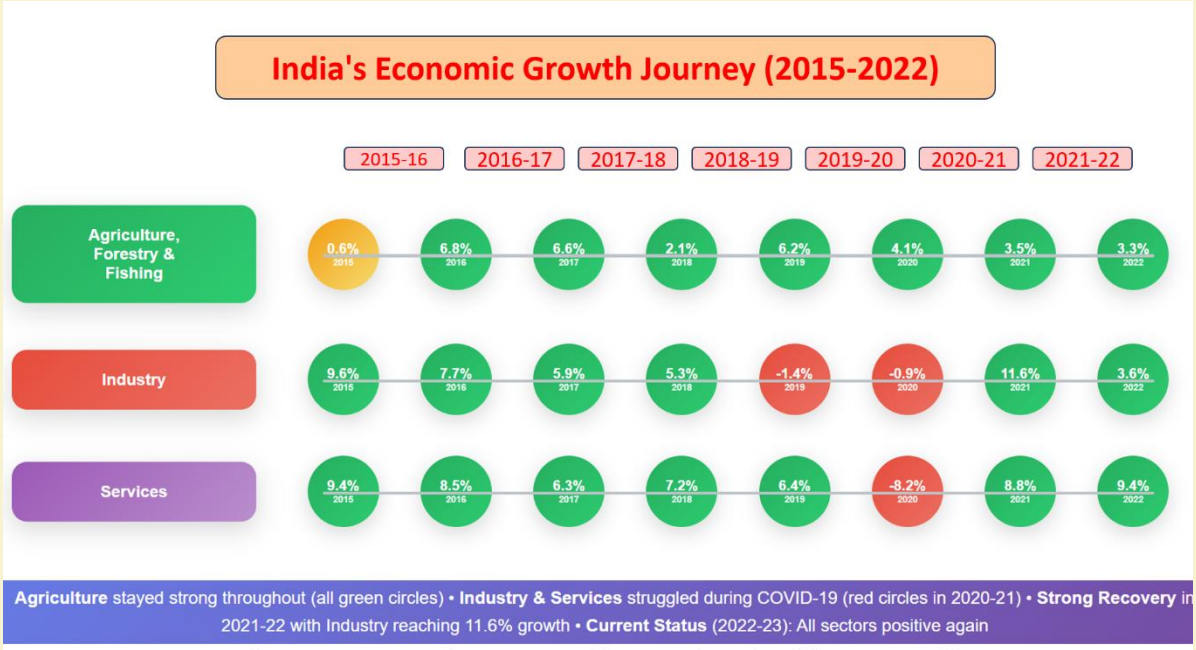


Fig. 2 Overall Status of Indian Agriculture



Source: *Directorate of Economics and Statistics, Agricultural Statistics at a Glance 2022*

Fig. 3 Indian Economic Growth Journey (2015-22)

Together, these interventions reflected a strategic shift toward technology-enabled, inclusive, and climate-resilient agriculture, aligning with national goals of doubling farmers' income and enhancing food system sustainability (Singh & Singh, 2025). Key policy initiatives in the current phase of Indian agriculture include PM-KISAN, which provides ₹6,000 annually to farmer families as direct income support, and PMFBY, offering crop insurance to mitigate

climate and disaster-related risks. Schemes like PKVY and MOVCDNER promote organic and natural farming, especially in ecologically sensitive regions. Technology-driven reforms such as e-NAM, AI-based advisory tools, subsidized drone usage, and support for FPOs and agri-startups have enhanced productivity, market access, and decision-making. These interventions contributed to a 3.8% growth in the agriculture sector in FY25, driven by record Kharif output and rising rural demand (Ministry of Agriculture & Farmers Welfare, 2025). The National Mission on Edible Oils-Oil Palm (NMEO-OP), launched in 2021, was designed to reduce India's heavy dependence on imported edible oils by expanding oil palm cultivation from 3.5 lakh hectares to 10 lakh hectares by 2025–26 (Department of Agriculture & Farmers Welfare, 2025). Despite its robust framework, implementation challenges such as poor nursery management, low fresh fruit bunch (FFB) yields, and inadequate irrigation have hindered progress, with only about 50% of the area target likely to be achieved. Complementing this, the Agriculture Export Policy emphasizes value-added exports, cluster-based development, and branding of indigenous commodities to boost India's agri-trade footprint. Meanwhile, the Production Linked Incentive (PLI) Scheme for Food Processing supports global-scale manufacturing of ready-to-eat foods, marine products, and organic items, with ₹10,900 crore allocated to strengthen Indian brands and enhance export competitiveness. Together, these initiatives reflect a strategic push toward self-reliance and global integration in the agri-food sector (Department of Commerce, 2018).

5. FOOD SYSTEMS: INDIA & GLOBAL STATUS

5.1 Pre-Production: Building the Foundation

Seeds: Quality Foundation for Productivity

India's seed sector demonstrates robust institutional capacity with ICAR producing over 1 lakh quintals of breeder seed in 2023-24, with increasing emphasis on climate-resilient varieties. The focus on developing drought-tolerant, heat-resistant, and pest-resistant varieties reflects strategic adaptation to climate change challenges (Committee on Estimates, 2025). Quality seeds account for 20%-25% of increased crop productivity, making them crucial for agricultural transformation. However, the adoption rate of improved seeds remains uneven across regions and crops, with smallholder farmers often facing accessibility challenges due to cost and distribution constraints (FICCI & YES BANK, 2024). The regulatory framework under the Seeds Act, 1966, governs seed quality standards, though recent reforms aim to

streamline seed certification processes and encourage private sector participation in variety development and distribution (Department of Agriculture & Farmers Welfare, 2004).

Fertilizers: Transition Towards Sustainability

The Indian fertilizer landscape is undergoing a paradigmatic shift with the introduction of Nano Urea and Nano DAP under the PM-PRANAM (PM Programme for Restoration, Awareness, Nourishment and Amelioration of Mother-Earth) scheme, targeting reduction in chemical fertilizer overuse while maintaining productivity levels. India's fertilizer production showed growth in fiscal year 2024, though at a decreased rate compared to the previous year's 11.3 percent (Ministry of Chemicals and Fertilizers, 2025). This transition represents a significant departure from the high-input model of the Green Revolution toward nutrient-efficient and environmentally sustainable fertilizer management. The challenge lies in addressing regional imbalances where some areas experience fertilizer overuse, leading to soil degradation and groundwater contamination, while others remain under-fertilized.

Manures & Organics: Sustainable Soil Management

The resurgence of organic farming through PKVY (Paramparagat Krishi Vikas Yojana) and MOVCDNER (Mission Organic Value Chain Development for North Eastern Region) reflects growing recognition of soil health and environmental sustainability. These schemes support the establishment of organic clusters and certification systems, facilitating farmers' transition to chemical-free production systems. Despite policy support, the scale of organic farming remains limited compared to conventional agriculture, requiring enhanced incentives and market linkages (Ministry of Agriculture & Farmers Welfare, 2025).

Plant Protection: Integrated Management Systems

The shift from chemical-intensive pest control to Integrated Pest Management (IPM) and biopesticide adoption marks a pivotal move toward sustainable agriculture in India. IPM integrates biological control agents, cultural practices, and judicious chemical use to maintain pest populations below economic threshold levels, minimizing ecological disruption and health risks (Ministry of Agriculture & Farmers Welfare, 2014). Biopesticides such as Trichoderma spp., Bacillus thuringiensis, and neem-based formulations have gained traction for their specificity and environmental safety, though they still account for less than 3% of total pesticide use (Ram, 2015). The Economic Survey of India 2024–25 underscores the importance of IPM and biopesticides in enhancing climate resilience, soil health, and farm profitability, especially

under the National Mission on Sustainable Agriculture. However, challenges persist in scaling adoption, particularly due to limited farmer awareness, technical training gaps, and market access for biocontrol inputs. Strengthening extension services, expanding biocontrol labs, and incentivizing public-private partnerships are critical to mainstreaming IPM across cropping systems (Ministry of Finance, 2025).

Credit: Expanding Financial Access

Institutional credit in Indian agriculture has expanded through schemes like Kisan Credit Card, interest subvention, and PMFBY, improving financial inclusion; however, non-institutional lending often exploitative still persists in rural areas, especially among smallholders (Reserve Bank of India, 2019). The Economic Survey (2025) notes that formal credit remains skewed toward crop production, leaving gaps in financing for allied activities like livestock and agro-processing due to collateral constraints and low financial literacy. Bridging this gap requires strengthening FPO and SHG linkages, promoting Joint Liability Groups, simplifying KCC norms for diversified farm operations, and digitizing land records to enhance credit access (Ministry of Agriculture & Farmers Welfare, 2025; Ministry of Finance, 2025).

Mechanization & Automation: Technology-Driven Transformation

The establishment of 26,662 Custom Hiring Centers (CHCs) by 2024 has significantly improved smallholder farmers' access to mechanization services without requiring individual ownership of expensive equipment. The provision of drones to Self-Help Groups (SHGs) with 80% subsidies represents innovative technology adoption for precision agriculture applications, including pesticide spraying and crop monitoring (Department of Agriculture & Farmers Welfare, 2025). AI-based precision farming systems are increasingly being integrated into agricultural operations, enabling data-driven decision making for optimal resource utilization, though adoption rates vary significantly across regions and farm sizes (Aijaz *et al.,* 2025).

Digitalization: Information and Market Integration

The digital transformation of agriculture through platforms like e-NAM (National Agriculture Market), Kisan Call Centers, and numerous agri-tech startups has revolutionized information access and market connectivity. Agri-data platforms provide real-time information on weather, market prices, and technical advisories, enhancing farmers' decision-making capabilities.

However, digital divide issues persist, with smallholder farmers in remote areas often lacking adequate digital infrastructure and technological literacy.

5.2 Production: Meeting Food and Nutrition Security

Cereals: Global Production Leadership with Productivity Challenges

India stands as the world's second-largest cereal producer, contributing significantly to global food security. However, productivity levels remain below global averages for many crops, indicating substantial potential for yield improvements. The global cereal production increased by 61 million tonnes (2 percent) between 2022 and 2023, driven primarily by increased maize output. Maize, wheat, and rice accounted for 91 percent of total cereal production in 2023 globally (Ministry of Finance, 2025). Rice and wheat continue to dominate India's production systems, though efforts to promote millets as "nutri-cereals" reflect recognition of nutritional diversity and climate resilience. The challenge lies in balancing food security objectives with dietary diversification and environmental sustainability, particularly in water-stressed regions (World Food Programme & NITI Aayog, 2024).

Pulses & Oilseeds: Addressing Protein and Oil Security

The National Food Security Mission prioritizes pulse production to reduce import dependence and improve protein availability in Indian diets. Despite significant increases in domestic pulse production, India continues importing substantial quantities to meet growing demand, indicating the need for further productivity enhancements and area expansion (Patel *et al.,* 2025). The National Mission on Edible Oils – Oil Palm (NMEO-OP) represents a strategic initiative to reduce the massive edible oil import bill, currently exceeding USD 20 billion annually. The mission focuses on expanding palm oil cultivation in suitable areas while addressing challenges, including water requirements, soil suitability, and environmental concerns (Ministry of Agriculture & Farmers Welfare, 2025).

Dairy: Global Leadership Story

India's position as the world's largest milk producer, with 230 million tonnes (MMT) in 2022-23, represents one of agriculture's most remarkable success stories. The cooperative model pioneered through Operation Flood created a robust dairy value chain connecting millions of smallholder farmers to urban markets, demonstrating the effectiveness of institutional innovations in agricultural development (Department of Animal Husbandry and Dairying, 2025). The dairy sector's continued growth reflects strong domestic demand driven by rising

incomes and dietary preferences, effective institutional mechanisms, and technological innovations in breeding, feeding, and processing. However, challenges include improving productivity per animal, ensuring quality standards, and addressing environmental concerns related to greenhouse gas emissions from livestock (Food & Beverages Processing, 2024).

Meat & Poultry: Rapid Growth Trajectory

India's poultry sector has recorded exceptional growth, making it the third-largest egg producer and fifth-largest broiler producer globally, with annual egg production reaching 136.5 billion and broiler meat output exceeding 4.8 million tonnes in FY 2023–24 (Department of Animal Husbandry & Dairying, 2024). This expansion is driven by rising protein demand, urbanization, and improved supply chains, contributing significantly to nutrition security and rural employment, especially through contract farming and backyard poultry. However, the sector faces challenges such as disease outbreaks (e.g., avian influenza), feed cost volatility with maize and soybean prices rising over 20% in recent years and infrastructure gaps in cold chains and hygienic processing, with over 90% of poultry meat still sold through wet markets (Rosero, 2024). Addressing these issues through biosecurity measures, feed innovation, and investment in modern retail and cold storage is essential to sustain growth and enhance the sector's role in India's agri-food economy.

Fishery: Blue Revolution Success

The Pradhan Mantri Matsya Sampada Yojana (PMMSY) significantly boosted India's fish production to 184 lakh tonnes in 2023, underscoring the sector's vital role in enhancing protein supply and supporting rural livelihoods. This growth spanned both marine and inland fisheries, with aquaculture emerging as a key driver of output. According to the Economic Survey 2024–25, India's fisheries sector expanded by over 104% since 2013–14, with inland fisheries alone growing by 142%, reflecting a strategic shift toward sustainable, high-yield aquaculture. Meanwhile, global marine fishery stocks within biologically sustainable levels declined to 62.3% in 2021 (Department of Fisheries, 2025), reinforcing the urgency of responsible fisheries management. India's emphasis on inland aquaculture, digital platforms, and ecosystem-based practices positioned it for continued growth while addressing environmental and resource sustainability concerns.

Technology & Resource Use: Precision Agriculture Adoption

The adoption of precision farming, micro-irrigation, and renewable energy marked a transformative shift toward resource-efficient agriculture in India. Technologies such as IoT sensors, AI-driven analytics, and satellite-based monitoring enabled farmers to make real-time decisions on irrigation, fertilization, and pest control, improving yields and reducing input waste (Yadav, 2024). Agritech platforms like AgriPilot.ai and Fyllo integrated these tools to support crop health monitoring, soil analysis, and predictive disease alerts. However, the Economic Survey 2024–25 noted that adoption remained uneven, with smallholder farmers facing barriers due to high costs, limited digital literacy, and inadequate extension services (Mahatma Gandhi Gramodaya University, 2024). Bridging this gap required targeted government support, localized tech solutions, and improved connectivity to ensure inclusive access to smart farming innovations.

5.3 Post-Production: Value Addition and Market Integration

Marketing: Connecting Farmers to Remunerative Markets

The agricultural marketing landscape has transformed significantly through the integration of Minimum Support Price (MSP) operations, Public Distribution System (PDS), and e-NAM platform connectivity. The MSP system covers 23 crops, providing price support to farmers, while PDS ensures food security for consumers. The e-NAM platform has created a unified national agricultural market, enabling farmers to access broader markets and realize better prices for their produce. The introduction of Kisan Rail services for transporting perishables has improved market access for farmers in distant locations, reducing transportation time and post-harvest losses (Ministry of Railways, 2025). However, infrastructure challenges persist in many areas, and the benefits of market reforms have not reached all farmers uniformly, particularly smallholders in remote regions.

Value Addition: Processing Sector Growth

The rise in India's food processing sector has been significantly propelled by schemes like the Pradhan Mantri Kisan Sampada Yojana (PMKSY) and the Production Linked Incentive Scheme for Food Processing Industry (PLIS-FPI), both aimed at enhancing infrastructure, boosting investment, and fostering innovation. PMKSY, with a total outlay of ₹5,520 crore (2021–2026), provides financial assistance for setting up processing units, while PLIS-FPI, with an outlay of ₹10,900 crore (2021–2027), supports the creation of global food

manufacturing champions and promotes Indian brands in international markets. These initiatives have positioned food processing as a vital link in the agricultural value chain, enabling farmers to realize better returns through value addition, reduced post-harvest losses, and expanded market access (Ministry of Food Processing Industries, 2025).The sector's growth reflects increasing consumer demand for processed foods, export opportunities, and the potential to reduce post-harvest losses. However, the processing level remains low for many agricultural commodities compared to global standards, indicating substantial scope for expansion and improvement.

Processing: Secondary Agriculture Development

Secondary agriculture in India has gained momentum as a strategic pathway for diversification and rural income enhancement, moving beyond conventional crop production. It encompasses sectors like floriculture, medicinal plant cultivation, and bio-based product manufacturing, each showing strong growth potential. As of 2023–24, India cultivated floriculture across 285 thousand hectares, producing 2,284 thousand tonnes of loose flowers and 947 thousand tonnes of cut flowers, with exports valued at USD 86.63 million. States like Tamil Nadu, Karnataka, and West Bengal lead in commercial floriculture, supported by polyhouse technologies and APEDA-backed export units. Additionally, initiatives under the National Medicinal Plants Board and bio-economy missions have promoted herbal cultivation and bio-product innovation, including essential oils, natural dyes, and biodegradable packaging (Department of Commerce, 2025). These developments reflect a shift toward value-added, climate-resilient agriculture, offering new avenues for entrepreneurship, employment, and sustainable growth. These activities often require specific infrastructure, technical knowledge, and market linkages, presenting both opportunities and challenges for farmers seeking to diversify their income sources.

Distribution: Export Performance and Market Access

India's agricultural export performance has shown remarkable improvement, reaching USD 46.44 billion in FY24, demonstrating the country's growing competitiveness in global markets. The Agri-Export Policy focuses on doubling agricultural exports by leveraging competitive advantages in various commodities, including rice, wheat, fruits, vegetables, spices, and marine products. The challenge lies in meeting stringent international quality standards, ensuring consistent supply, and competing effectively in global markets characterized by intense

competition and complex regulatory requirements. Infrastructure development for quality maintenance and certification processes remains critical for sustained export growth.

Storage & Warehousing: Infrastructure Modernization

India's post-harvest infrastructure witnessed major modernization in 2024, with 48,611 storage projects sanctioned, reflecting a strategic push to reduce losses and enhance supply chain efficiency. The adoption of Hub & Spoke silo systems and Smart Warehousing models introduced advanced technologies such as automated temperature and humidity control, digital pest management, and real-time inventory tracking. These upgrades align with the goals of the National Logistics Policy and PM Gati Shakti, which aim to streamline agri-logistics and integrate rural producers into national value chains. According to recent industry reports, India's warehousing sector expanded by 35% year-on-year, reaching 19.1 million sq. ft. in H1 2023, with third-party logistics (3PL) players driving 43% of leasing activity. This transformation positions India to become a global agri-logistics hub while ensuring better price realization and reduced wastage for farmers (Gada, 2024a; Gada, 2024b). These investments aim to address the critical infrastructure gap that has historically led to substantial post-harvest losses, particularly affecting farmers' incomes and contributing to food price volatility.

Infrastructure: Cold Chain and Support Systems

The development of cold chain networks and support through the Agri-Market Infrastructure (AMI) scheme provides subsidies for creating temperature-controlled storage and transportation facilities, particularly crucial for perishable commodities including fruits, vegetables, dairy products, and meat (Badatya & Prasad, 2010). Despite significant investments, infrastructure gaps persist, particularly in remote agricultural areas where farmers lack access to proper storage facilities. The integration of renewable energy systems in cold storage and the development of mobile cold storage units represent innovative approaches to addressing these challenges. The success of infrastructure development depends not only on physical infrastructure but also on developing technical capacity, maintenance systems, and financial sustainability models for long-term operation and effectiveness.

Global Context and Comparative Perspective

India's agricultural shift was shaped by global pressures like climate change, population growth, and changing diets. The FAO (2024) reported rising land temperatures, persistent food insecurity, and growing obesity over 25% of adults in the Americas, Europe, and Oceania were

obese. In this context, India needed to adopt sustainable, tech-driven, and inclusive strategies to ensure food and nutrition security. The country's experience in achieving food self-sufficiency, developing cooperative institutions, and leveraging technology provides valuable lessons for other developing nations (Indian Agricultural Research Institute, 2011). However, challenges including climate change adaptation, natural resource conservation, and ensuring equitable growth require continued policy attention and innovative solutions. The integration of traditional knowledge with modern technology, promotion of sustainable farming practices, and strengthening of rural institutions remain essential for India's agricultural future. The path forward requires balancing productivity growth with environmental sustainability, ensuring that the benefits of agricultural development reach all segments of the farming community, and positioning Indian agriculture to contribute effectively to global food security while meeting the nutritional needs of its growing population.

Table 1: India's global ranking in staple foods

Category	**Crop / Product**	**India's Global Rank**	**Production / Volume**
Cereals & Staples	Rice	2nd	157.58 million tonnes
Cereals & Staples	Wheat	3rd	Major producer (13% global)
Cereals & Staples	Maize	5th	Increasing (4% global)
Pulses & Legumes	Pulses (Total)	1st	Largest producer (25% global)
Roots & Tubers	Potato	2nd	Major staple (15% global)
Sugar & Bio-crops	Sugarcane	2nd	Major sugar producer (20% global)
Oilseeds	Soybean	5th	Increasing (2% global)
Horticulture – Fruits & Vegetables	Fruits (Total)	2nd	Diverse fruit basket (12% global)
Horticulture – Fruits & Vegetables	Mango	1st	Largest (45% global)
Horticulture – Fruits & Vegetables	Banana	1st	Largest (25% global)

Horticulture – Fruits & Vegetables	Onion	2nd	Major exporter (20% global)
Horticulture – Fruits & Vegetables	Tomato	2nd	Large production (12% global)
Horticulture – Fruits & Vegetables	Vegetables (Total)	2nd	Major producer (15% global)
Dairy & Milk Products	Milk (Total)	1st	216.22 million tonnes
Dairy & Milk Products	Butter & Ghee	1st	Largest (30% global)
Dairy & Milk Products	Cheese	Not Top-3	Small share (<2%)
Poultry & Eggs	Eggs	2nd	153.5 billion eggs
Poultry & Eggs	Chicken Meat	5th	5.6 million tonnes
Fisheries & Aquaculture	Fish (Total)	2nd	10.2 million tonnes
Fisheries & Aquaculture	Aquaculture	2nd	Growing rapidly (8% global)
Fisheries & Aquaculture	Marine Fisheries	3rd	Important (6% global)
Livestock & Meat	Buffalo Meat	1st	Largest exporter 40% global)
Livestock & Meat	Goat Meat	2nd	Large population (18% global)
Special Crops & Fibers	Tea	2nd	Major exporter (25% global)
Special Crops & Fibers	Coffee	5th	Arabica & Robusta (4% global)
Special Crops & Fires	Cotton	2nd	Large textile feedstock (24% global)
Special Crops & Fibers	Jute	1st	Largest (60% global)
Special Crops & Fibers	Spices (Total)	1st	Largest producer (46% global)

CONCLUSION

This study concluded that Indian agriculture had transitioned from pre-independence subsistence farming and famines to a diversified, technology-driven system marked by self-sufficiency in cereals, global leadership in milk (230 million tonnes in 2022–23), and rapid growth in fisheries (184 lakh tonnes in 2023). Despite these achievements, the sector's GDP share declined to 18% by 2019, while it continued to employ over 40% of the workforce, reflecting a widening productivity gap. Household-level analysis showed that 87% of farm families earned less than ₹10,000 monthly, with stark inter-state disparities only 1% of households in Jharkhand earned above this threshold compared with 74% in Punjab. Globally, agriculture employed over 1.06 billion people in 2019, indicating its persistent role in livelihoods despite structural shifts toward services. India's post-liberalization reforms spurred diversification into horticulture, poultry, and aquaculture, while recent digital innovations such as e-NAM linking 1,470 mandis, and the FPO scheme with 44,000 groups formed by 2025 strengthened market access and farmer collectives. However, challenges including low productivity in pulses and oilseeds, climate vulnerabilities, and uneven adoption of mechanization and digital tools persisted. Overall, the findings suggested that India's future agricultural trajectory required an integrated strategy linking productivity growth with ecological sustainability, equitable income distribution, and global competitiveness to secure food and nutrition security for its population.

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Status of India Global Hunger Index SDGs: Challenges and Initiatives

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Abstract

As a means to monitor hunger globally, regionally, and nationally, the Global Hunger Index (GHI) gauges certain dimensions of hunger through time. The Global Hunger Index (GHI) compares hunger levels across nations and regions in an effort to raise awareness and understanding of the battle to eradicate hunger and to identify where in the world hunger is the worst and where the greatest urgency is needed to end hunger. India is ranked 105th out of 127 countries with a serious score of 27.3, according to GHI 2024 data. Food supply and agricultural output are at risk due to climate change, which introduces an additional layer of risk. To ensure long-term resilience in this setting, crop diversity, climate-smart agriculture, and sustainable agricultural methods are essential. Global best practices that have been successful in reducing hunger and undernutrition include Vietnam's focused agricultural reforms and Bangladesh's community-driven nutrition programs. Enhancing nutrition education, empowering women as important home nutrition agents, and increasing the transparency of subsidy administration are all necessary to strengthen food security in India. A holistic, multidisciplinary strategy that blends agriculture, health, and protection for society is crucial. Food supply and crop production are at risk due to climate change, which introduces a further layer of risk. To ensure long-term resilience in this setting, crop diversity, climate-smart agriculture, and sustainable agricultural methods are essential.

Keywords: Challenges, Climate-smart, Community-driven, Global Hunger Index, Holistic, Initiatives, Indicators, Multidisciplinary.

Introduction

The GHI is a tool that can be used for measuring hunger and monitoring hunger at the global, national, or regional level. The GHI is a composite index that examines hunger in various contexts by combining multiple indicators to conclude. The GHI not only determines where needs exist most, but it also aims to provide a rounded picture of hunger. Apart from India, the

other countries like Pakistan, Bangladesh, Nepal, and Sri Lanka stand at 102, 81, 69, and 60 ranks respectively. According to the 2024 GHI scores, there are 36 severe countries and six alarming countries, including Burundi, Chad, Madagascar, Somalia, South Sudan, and Yemen. In 22 countries, hunger has worsened with alarming, serious, or worrying scores, while progress has been stagnant in 20 countries.

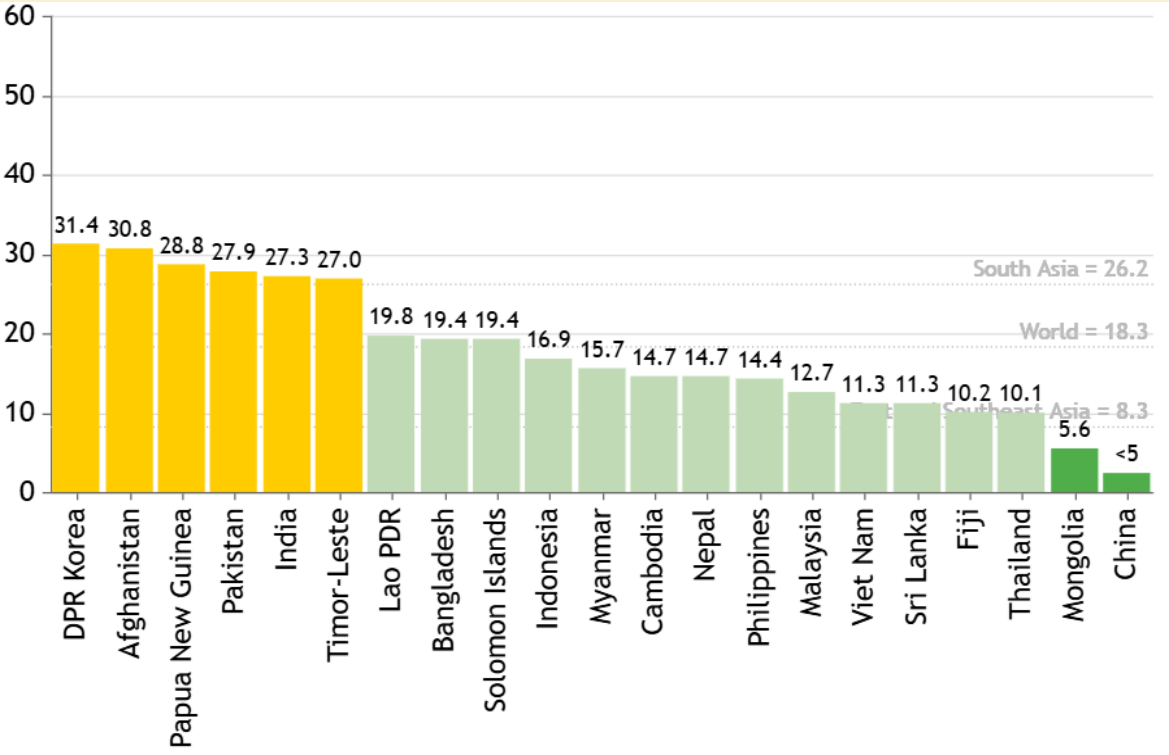

Fig. 1. 2024 GHI scores in South, East, and Southeast Asia (Source: Global Hunger Index, 2024)

It indicates the GHI scores in countries like DPR Korea(31.4), Afghanistan(30.8), Papua New Guinea(28.8), Pakistan(27.9), India(27.3), Timor-Leste(27.0), Lao PDR(19.8), Bangladesh(19.4), Solomon Islands(19.4), Indonesia(16.9), Myanmar(15.7), Cambodia(14.7), Nepal(14.7), Philippines(14.4), Malaysia(12.7), Viet Nam(11.3), Sri Lanka(11.3), Fiji(10.2), Thailand(10.1), Mongolia(5.6), China(<5) (Fig.1).

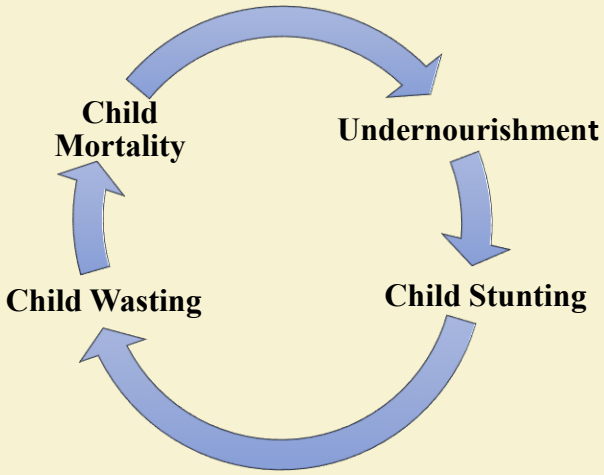

Fig. 2. Four Components of the Indicator

Undernourishment: A person is considered undernourished if, over the course of a year, the individual is unable to obtain enough food to meet their daily minimum dietary energy requirements. According to the FAO, hunger is synonymous with chronic undernourishment (Fig.2).

Child Stunting: As defined by WHO, low height-for-age is known as stunting. It is caused by chronic or repeated undernutrition, which is typically associated with low socioeconomic status, poor nutrition and health of mothers, a high rate of sickness, and/or improper early feeding and care of infants and young children. Children who are stunted are unable to develop to their full physical and cognitive potential (Fig.2).

Child Wasting: As defined by WHO, low weight-for-height is known as wasting. Severe malnutrition is evident in the proportion of children under five who weigh less than their height, leading to increased child mortality. Although there is a higher chance of death for a young child who is moderately or severely wasted, treatment is possible (Fig.2).

Child Mortality: The high mortality rate in children before turning five is largely due to a combination of poor diet and unhealthy surroundings (Fig.2).

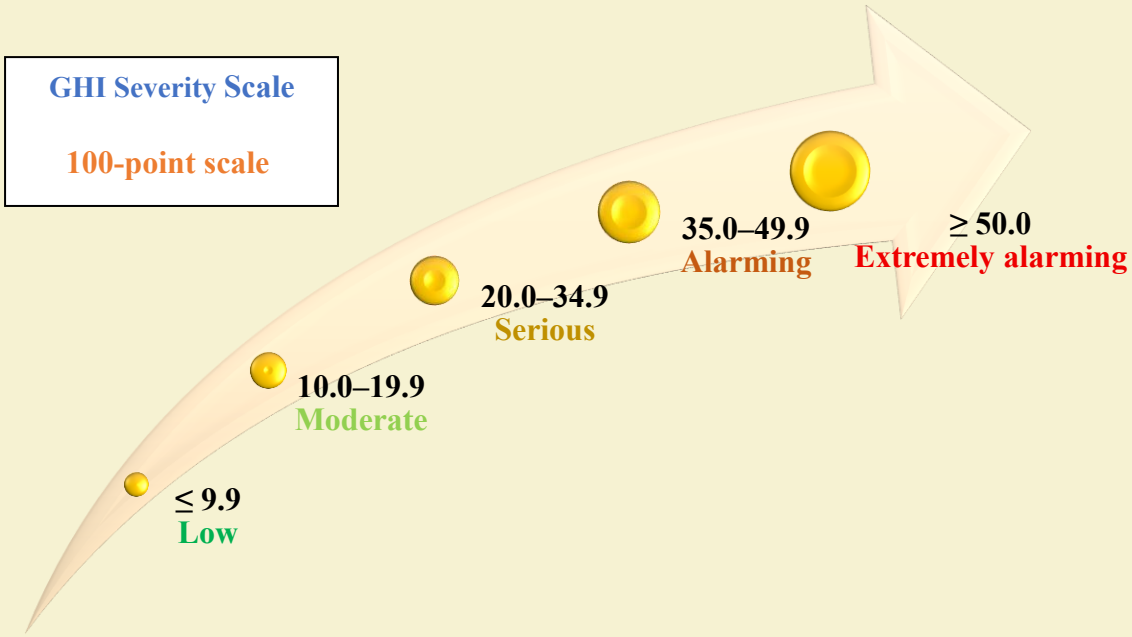

Fig. 3. GHI Severity Scale (Source: GHI,2024)

It denotes the level of severity of the Global Hunger Index, with a low level being ≤ 9.9 and an extremely alarming level being> 50.0 (Fig. 3).

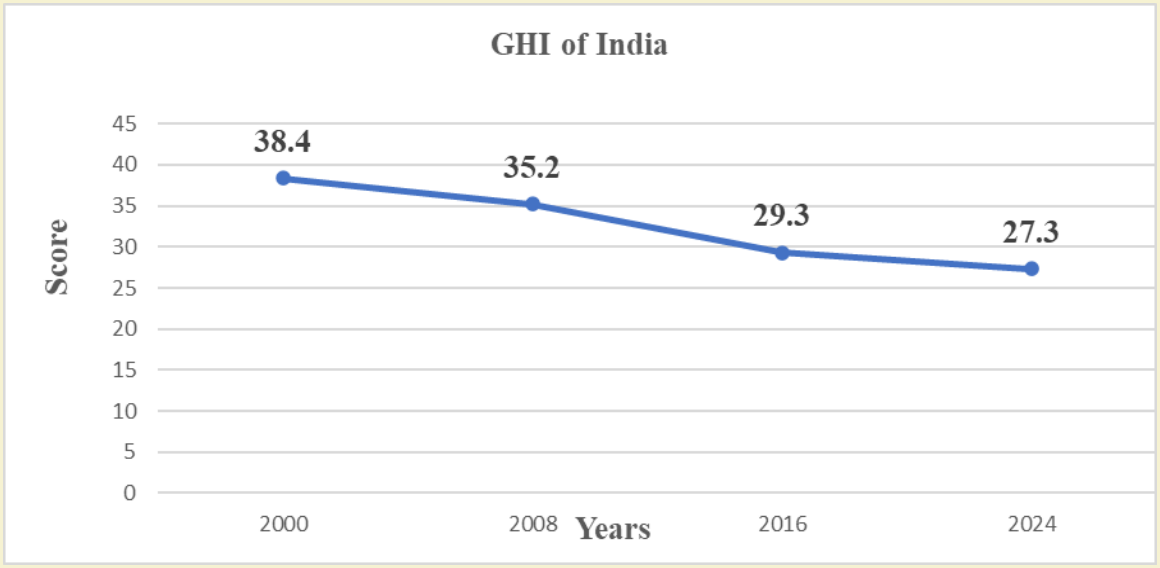

Fig. 4. Scores on the GHI of India (Source: GHI, 2024)

It denotes Scores on the GHI of India in a decreasing order from 2000 to 2024, from 38.4 to 27.3(Fig.4).

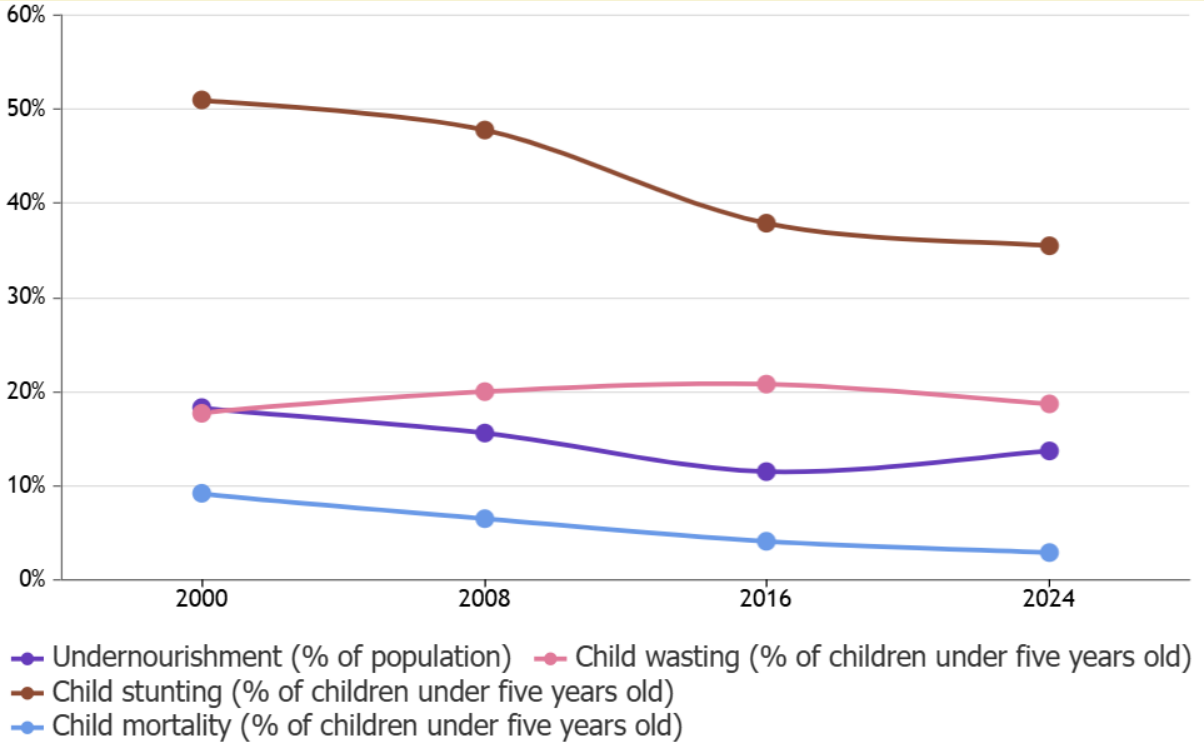

Fig. 5. Trend for indicator values-India (Source: Global Hunger Index)

It indicates the population percentage of Undernourishment, Child Wasting, Child stunting, and Child mortality (Fig.5).

The Government of India's Measures to Reach SDG 2

To achieve food security in the country, the Government of India has launched different schemes. Some of the key schemes are-

- **Public Distribution System (PDS):** PDS is a food security system run by the government of India that subsidizes food grains and other necessities for households below the poverty line, purchasing them from farmers at minimum support rates.
- **National Food Security Act (NFSA):** The National Food Security Act was enacted on July 5, 2013. The act provided legal entitlement to households living below the poverty line (BPL) to receive subsidized food grains. With rice, wheat, and coarse grains priced at Rs. Three, Rs. Two, and Rs. One per kg, respectively, the act aimed to provide AAY families with 35 kg of foodgrains per family per month. Moreover, each person in priority households is entitled to 5 kilograms of foodgrains each month.

- **Mid-Day Meal Scheme (MDMS):** The MDMS school meal program distributes free lunches to primary school students, aiming to enhance attendance, retention, and food security for low-income children.
- **Integrated Child Development Services (ICDS):** This program provides assistance to under-six children, pregnant women, and breastfeeding mothers to improve their nutritional status and health. In this program, there is preschool education, health assessments, immunizations, and supplementary food.
- **Pradhan Mantri Fasal Bima Yojana (PMFBY):** PMFBY is a farmer insurance scheme that provides subsidized crop insurance and monetary compensation in the event that crop damage occurs as a result of a natural disaster.
- **National Agricultural Market(e-NAM)**: The Prime Minister of India launched the e-National Agriculture Market (e-NAM), an online marketplace that serves all of India, on April 14, 2016. e-NAM seeks to integrate all of the country's existing Agricultural Produce Market Committees (APMC) mandis into a single online marketplace, facilitating "One Nation One Market."
- **Pradhan Mantri Kisan Samman Nidhi (PM-KISAN):** PM-KISAN is a Central Sector initiative that is fully funded by the Indian Government, as direct income support of Rs. 6,000 per year offers an economic subsidy to all beneficiary farmer-member households owning cultivable land.
- **Mission POSHAN 2.0:** This Mission combines the previous POSHAN Abhiyaan with aligned initiatives to form a collective nutrition mission that reinforces action on nutrition. It also consists of supporting nutrition gardens, with plans for fortified rice kiosks on a national scale, highlighting the crucial 1,000-day window, which spans from conception until the child's second birthday, and stepping up efforts in districts with aspirations.
- **Jharkhand Smartphone-Enabled Anganwadi:** Jharkhand has provided Smartphone technology in Anganwadi service delivery. This technology aided Aadhaar-authenticated access that enabled real-time tracking of the beneficiaries' pregnant women, lactating women, and children to improve nutrition delivery using facial recognition and video consultations.
- **Rice Fortification & Nutrition Security:** Between 2019–20 and March 2024, the government of India made use of the Public Distribution System (PDS) to distribute about

406 lakh metric tonnes of fortified rice in an effort to address hidden hunger through micronutrient consumption.

- **Operation Greens (TOP Crops Stabilization):** This ₹500-crore scheme under the 2018-19 budget has the objective of stabilizing the prices of tomatoes, onions, and potatoes (TOP) by subsidizing handling and storage facilities. Building the capacity of FPOs, carrying out logistics, storage, processing, and market access have been effective approaches for farmers producing TOP.

- **Food grain Storage Expansion through Cooperatives:** Using a ₹1 lakh crore budget, the government began what is seen as the world's largest project using a cooperative-based approach to store food grains by erecting high-capacity godowns with a capacity of 2,000 tons each in every block. This project will help reduce distressed sales and post-harvest losses, besides building rural infrastructure.

- **Gramin Bhandara Yojana - Rural Storage Subsidies:** Gramin Bhandara Yojana-Rural Storage Subsidies or Sometimes called the Rural Godown Scheme, the Gramin Godown Scheme allows for the provision of financial assistance for the construction or repair of rural godowns (ranging in size from 100 to 30,000 tonnes), with the intention of giving small farmers better access to storage and more bargaining power, including farmers that live in hilly and difficult-access areas.

- **Atal Bhujal Yojana - Sustainable Groundwater Management:** To improve rural communities' access to irrigation and agricultural resilience, the World Bank-funded program, which was introduced under the Jal Jeevan Mission in December 2019, aims to conserve groundwater in seven priority states through community-based efforts.

- **Millets' Nutri cereal promotion:** In 2018, India declared the year to be the National Year of Millets, with a formal saying of Nutri cereals as being sorghum and millets. Millets were thereafter added to the Mid-Day Meal programs. This brings back ancient crops that are resilient, very high in nutrients, and require less water.

- **Digital Agriculture Mission (Agri Stack, DSS, Soil Mapping):** The ₹2,817 crore project, launched in 2024, includes a physical Krishi Decision Support System, digital IDs for farmers (via Agri Stack), and mapping of soil profiles across 142 million hectares to facilitate data-based decision-making and increase productivity.

- **Namo Drone Didi Scheme:** From 2024 to 2026, women self-help groups (SHGs) will have permission to use drones to conduct agricultural tasks, including the spraying of fertilizers and pesticides under this ₹1,261 crore scheme. The project enhances women's access to technology, income, and empowerment.
- **Smart-PDS & One Nation One Ration Card (ONORC):** The ONORC plan, which permits ration-issuing cards to be leveraged across all of India, and the SMART-PDS system (POS machines; Aadhaar/DBT connection; GPS/SMS tracking) are recent initiatives that have helped promote better access and transparency.
- **Climate-Smart Agriculture Mission:** The goal of the Climate-Smart Agriculture mission is to adapt food systems to climate change, which includes promoting low-emission farming practices, advancing effective irrigation, and drought-resistant crops.
- **Urban Nutrition Hubs:** To target slum populations, pilot projects in Bengaluru, Delhi, and Mumbai are connecting food banks, PDS locations, and community kitchens.
- **Public-Private Partnerships for Food Fortification:** Partnerships with the industrial sector to add vitamins and minerals to milk, wheat flour, and edible oil.
- **School-Based Kitchen Gardens:** To improve dietary diversity, schools are encouraged to grow fruits and vegetables for midday meals under PM POSHAN.
- **Farmer Producer Organization (FPO) Support Scheme:** Enhancing market connections and collective bargaining to raise farmer incomes and ensure food security.
- **Mobile Ration Delivery Vans:** Deployed to deliver subsidized food grains to homes in isolated and steep regions.
- **Nutrition Awareness Campaigns:** Campaigns like "Eat Right India," which are organized by the community and the media, encourage balanced, healthful diets and discourage highly processed foods.
- **Digital Nutrition Tracking Platforms:** Mobile-based solutions that monitor a child's development and connect incidents of malnutrition to medical care.

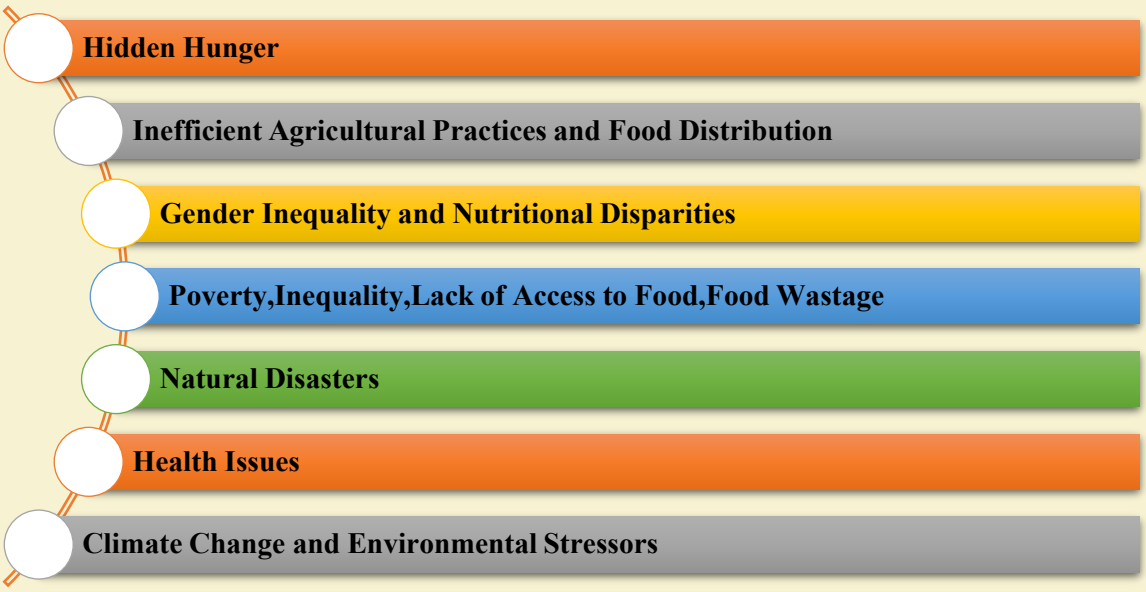

Fig. 6. Factors Contributing to Hunger in India

It indicates the various factors that contribute to hunger in India (Fig. 6).

India's reaction to GHI 2024

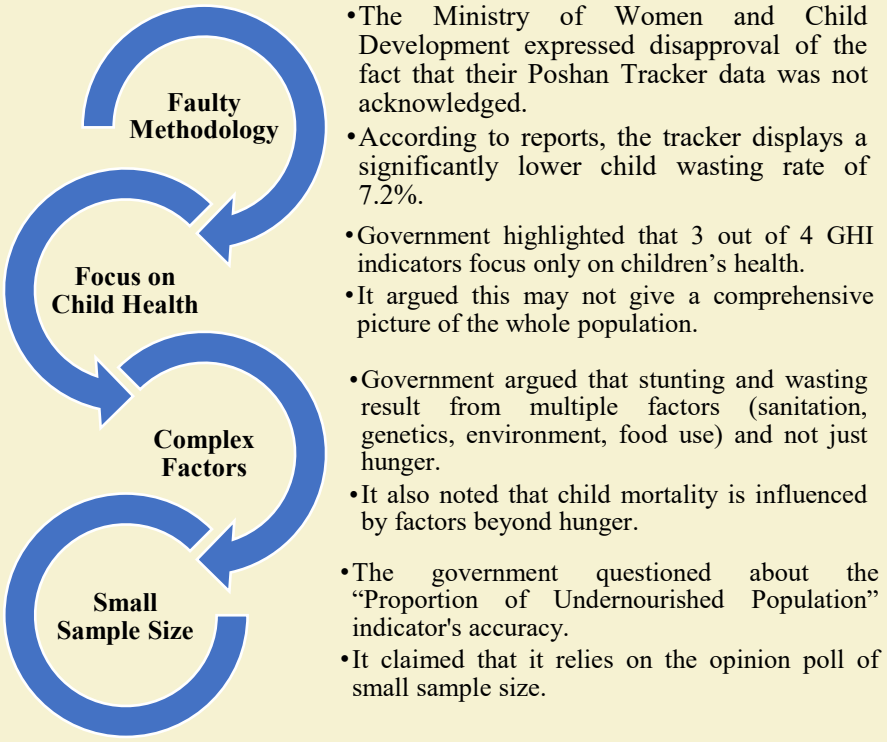

Fig. 7. Government feedback on GHI 2024

It indicates the Indian Government's reaction to GHI 2024 (Fig.7).

Which initiatives are being taken by the Indian government to combat hunger?

❖ **Eat Right India Movement:** The Food Safety and Standards Authority of India (FSSAI) is leading the *Eat Right India* campaign to reform the country's food system with the goal of making food safe, nutritious, and sustainable for everyone. This program is consistent with the goals of the National Health Policy 2017 and is linked to important government initiatives, including the Swachh Bharat Mission, POSHAN Abhiyaan, Anemia Mukt Bharat, and Ayushman Bharat. It uses a combination of partnerships, community empowerment strategies, capacity-building approaches, and regulatory actions to promote food that is good for the people as well as the environment.

The Related Initiatives:

- **State Food Safety Index:** To evaluate the performance of the state in five food safety indicators—compliance, infrastructure, surveillance, food testing, training, human resources, and consumer empowerment, the FSSAI developed the State Food Safety Index.
- **Eat Right Awards:** To appreciate the contributions of food businesses and individuals in encouraging safe and healthy food choices, FSSAI created the Eat Right Awards program.
- **Eat Right Mela:** To encourage the community to eat healthily, the FSSAI organizes this outreach program.

❖ **POSHAN Abhiyan (National Nutrition Mission):**

Launched in the year 2018, the National Nutrition Mission (POSHAN Abhiyaan) uses technology, behavioral change, and Swasth Bharat Preraks to reduce low birth weight, stunting, undernutrition, and anemia in early children, women, and teenage women by 2% annually.

❖ **POSHAN 2.0:** The government has integrated initiatives like POSHAN Abhiyaan and Supplementary Nutrition Program under Mission POSHAN 2.0 to enhance operational synergies and integrate the nutrition services framework.

Components of POSHAN 2.0:

1. **Consolidation:** To enhance efficiency and coordination, the government has merged various initiatives with common goals—such as POSHAN Abhiyaan and the Supplementary Nutrition Program—into *Mission POSHAN 2.0*. This integration is

intended to strengthen synergies and ensure a more unified approach to delivering nutrition services.

2. **Behavioral change:** To achieve the goal of mass participation, the Abhiyaan would be conducted as a Jan Andolan. Once a month, a community-based event will take place to address issues and raise awareness.
3. **Incentives:** Performance-based incentives will be provided to frontline employees.
4. **Training and Capacity Building:** Twenty-one theme modules will be taught using the incremental learning approach. Frontline employees will receive the instruction from Master Trainers.
5. **Grievance Redressal:** To make it simple to find answers to any problems encountered, a call center will be established.

❖ **The main topic of the question is Poshan Abhiyan's requirement.**

Malnutrition and Anemia in Children: Although there has been a slight improvement in stunting in India, it remains unacceptable, as indicated by the National Family Health Survey (NFHS)-5. 32.1% of children under five were underweight, and 35.5% of children were stunted in 2019–21.

Global Nutrition Report-2021: As stated by the Global Nutrition Report (GNR, 2021), India's rates of anemia and childhood wasting have not improved. Over 17% of Indian children under five are affected by childhood wasting. Maximum increase in anemia was observed in children aged between 6-59 months, going from 58.6% (NFHS-4, 2015–16) to 67.1% (NFHS-5) to according to NFHS-5 (2019–21) data.

Human Capital Index (2020): India is placed 116th out of 180 countries in the ranking. Human capital is all of the skills, health, and knowledge that people acquire over the course of their lives and that enable them to fulfill their potential as valuable contributors to society.

Which additional initiatives are related?

1. Anemia Mukt Bharat Abhiyan.
2. The National Food Security Act (NFSA), 2013.
3. Pradhan Mantri Matru Vandana Yojana (PMMVY).
4. PM-POSHAN Scheme.

- **Mid-day Meal (MDM) scheme:** The PM Poshan Shakti Nirman program, launched in 1925, is the world's largest school feeding program for underprivileged children in Government schools. It aims to increase school enrolment and was upgraded to Class 8 in 2007. The program covers 11.80 crore children aged 6-14.
- **Legal Entitlement:** Children in primary and upper primary schools are guaranteed food security under the National Food Security Act (NFSA) 2013, with a 60:40 cost-sharing arrangement with the central government. For the northeastern states, Uttarakhand, Himachal Pradesh, and Jammu and Kashmir, a 90:10 ratio is shared.
- **Pradhan Mantri Matru Vandana Yojana:** Starting January 1, 2017, a national maternity benefits program is implemented in each district, providing cash benefits to pregnant women who have lost wages. The program ensures timely, accountable, and equitable rewards for all women through the use of the Pradhan Mantri Matru Vandana Yojana-Common Application Software (PMMVY-CAS) monitors the program's beneficiaries.

Eligible Beneficiaries of PMMVY?

The plan offers eligible pregnant women and lactating mothers (PW&LM) a monetary benefit of Rs. 5,000 (paid in three installments) for their first child, in case the pregnancy commenced on or after January 1, 2017. The eligibility excludes women who are regular government/PSU employees or women availing similar benefits. Eligibility criteria for receiving the benefit are registration of pregnancy at an early stage, pre-natal check-ups during the pregnancy period, registration of the child's birth, and at the end of the 1st vaccination cycle for the 1st live child. Apart from this, beneficiaries may receive cash benefits under Janani Suraksha Yojana (JSY), other than the first installment, which makes the average total cash incentives around ₹ 6,000.

National Food Security Act, 2013: Food security encompasses more than just two meals, encompassing multiple dimensions, and is crucial for living as air is vital for breathing.

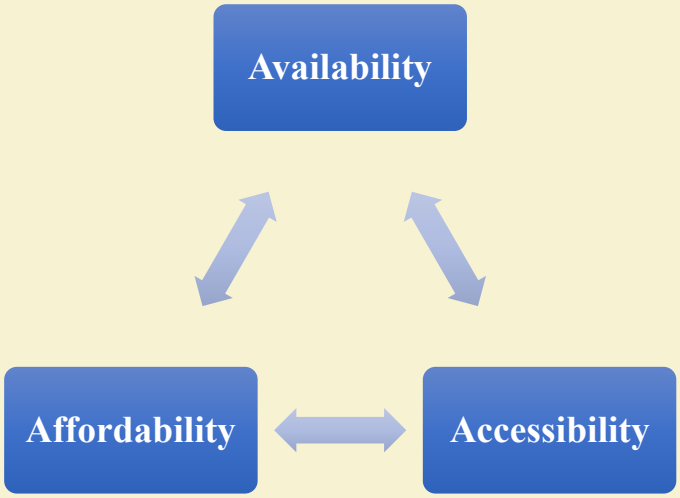

Fig.8. 3A's of National Food Security

Therefore, a country's food security is guaranteed only if there is an adequate supply of food for all individuals, if everyone is able to acquire food of acceptable quality from a source they can access, and if their access is free (Fig.8).

What is India's current food security framework?

Constitutional Provision: Although it is not specifically stated in the Constitution of India, the right to live with human self-esteem, which may comprise the right to food and other essentials, can be seen as part of the ultimate right to live, which is protected by Article 21 of the Constitution of India.

Buffer Stock: The Food Corporation of India (FCI) is the main authority primarily accountable for purchasing food grains at the minimum support price (MSP), storing them in various warehouses, and then selling them to state governments according to their specifications.

- **National Food Security Act, 2013 (NFSA):** It marks a shift in perspective about food security from a welfare-based approach to a rights-based approach. 75% of persons in rural areas and 50% of individuals in cities are covered under NFSA.
- **Antyodaya Anna Yojana:** The individuals considered to be the poorest of the poor are eligible to 35 kg of food grains/home/month.
- **Priority Households (PHH):** Households under the PHH group receive 5 kg of food grains monthly, with ration cards issued by the eldest woman. Children aged 6-14 can access healthy meals at no cost through Anganwadi Centers or ICDS centers.

- **Mission Indradhanush:** Intensified Mission Indradhanush (IMI) 4.0 was launched virtually by the Ministry of Health.

India's Universal Immunization Program (UIP), which immunizes over three crore pregnant women and 2.6 crore children annually, is one of the largest immunization programs in the world.

Challenges related to food security in India:

- **The deteriorating health of the soil:** Healthy soil is an important part of food production because it is necessary for about 95% of the world's food output.
- **Soil degradation:** Use of excessive agrochemicals, deforestation, and natural catastrophes pose a major danger to sustainable food production. On Earth, about one-third of the soil has already degraded.
- **Invasive Weed Threats**: Due to excessive or inappropriate use of agrochemicals, deforestation, and natural catastrophes represent a major danger to sustainable food production. On Earth, about one-third of the soil has already degraded. There were reports of locust attacks in Gujarat and Rajasthan districts in 2020.
- **Absence of an Efficient Management Framework**: India is deficient in a comprehensive structure for managing food security. There are challenges associated with the Public Distribution System, including leakages of food grains and diversions, incorrect inclusions and exclusions, fake and fraudulent ration cards, and a weak grievance redressal and social audit mechanism.
- **Lack of Storage facilities:** Because of a minimum support price, farmers have shifted their land from growing coarse grains to growing wheat and rice. In addition, there is an enormous yearly waste of about Rs. 50,000 crores due to both poor accounting and insufficient storage facilities.
- **Climate Change:** Approximately 60% of India's net cultivated area is irrigated by the monsoon, which is responsible for about 70% of the total annual precipitation in the country. India's agricultural productivity is already declining because of the changes in rainfall patterns, as well as increased occurrence and severity of extreme weather events such as hot spells and floods, that pose a serious threat to food security. The Indian

government has prohibited the export of broken rice to boost domestic supply in light of the low Kharif Crop output this year (2022).

- **Disruption in the Supply Chain Due to an Unstable Global Order:** The Russia-Ukraine War of 2022 has interrupted the supply chain, causing food shortages and inflation at a time when the world's food had already been disrupted by the Covid-19 Pandemic in 2020. 26 countries, mostly in Africa, West Asia, and Asia, rely on these two nations for at minimum half of their wheat imports, and 27% of the world's wheat market.

What is IMI 4.0?

Guaranteed routine immunization (RI) services for children who were not immunized or who were only partially vaccinated, as well as prenatal mothers. Children under the age of two will also be the focus of this vaccination campaign. IMI 4.0 will be a significant chance to decrease the vaccination gap and move closer to attaining long-term universal immunization coverage, even though the COVID-19 pandemic has hampered the progress of routine immunization (RI). There will be three rounds of IMI 4.0 in 416 districts in addition to the 75 districts selected for Azadi ka Amrit Mahotsav throughout 33 states and Union Territories. The districts were selected considering the vaccination coverage, Health Management Information System (HMIS) statistics, and the burden of vaccine-preventable diseases according to the most recent report of the National Family Health Survey-5.

Universal Immunization Program

The Ministry of Health and Family Welfare introduced the Indian immunization program in 1978 under the term "Expanded Program of Immunization (EPI)." The program was renamed as "Universal Immunization Program (UIP)" in 1985. Children and expectant women can receive vaccinations against 12 vaccine-preventable diseases through UIP. It has been noted, meanwhile, that the rate of improvement in vaccine coverage is still improving, albeit at a rate of 1% per year (2009-2013). In order to quickly raise the vaccination rate to 90%, Mission Indradhanush was developed and put into action in 2015.

Mission Indradhanush (MI)

More than 89 lakh youngsters who were partially or totally unimmunized were to be fully immunized under UIP. Measles-rubella (MR), rotavirus vaccine, pneumococcal conjugate vaccine (PCV), hepatitis B, diphtheria, Pertussis, tetanus, polio, tuberculosis, meningitis and

pneumonia, and Haemophilus influenzae type B infections are a few Vaccines Preventable Diseases (VPD) that vaccination is supported against. Additionally, immunization programs against Japanese encephalitis and Haemophilus influenzae type B have been made available in select regions of the nation. These are the key initiatives under the Gram Swaraj Abhiyan, and the Extended Gram Swaraj Abhiyan was Mission Indradhansuh.

Intensified Mission Indradhanush (IMI)

It was made available in October 2017. One of Mission Indradhanush's shortcomings was that IMI was primarily concerned with metropolitan regions. In order for more than 90% of individuals to be fully vaccinated by December 2018 rather than 2020, it was intended to raise vaccination rates in a few states and districts.

Intensified Mission Indradhanush 2.0: What is it?

A statewide immunization campaign was conducted to mark the Pulse polio program's 25th anniversary (2019–20). One of its objectives was to achieve full immunization coverage throughout 27 states and 272 districts. By 2022, a countrywide vaccination rate of at least 90% is anticipated.

Intensified Mission Indradhanush 3.0: What is it all about?

In 2021, IMI Version 3.0 launched. The IMI 3.0 focused on pregnant women and children who had not received their vaccinations during the COVID-19 outbreak. Because they might have missed their vaccination dose during COVID-19, recipients of migrating regions, as well as the underprivileged areas, were specifically targeted.

What Have We Done Thus Far?

Mission Indradhanush, a five-phase program, vaccinated 3.86 crore kids and 96.8 lakh expectant women, improving overall immunization coverage by 6.7% in a year. A survey showed an 18.5% increase in full vaccination coverage.

The program for Integrated Child Development Services (ICDS):

ICDS: What is it?

The ICDS, the Department of the Ministry of Women and Child Development, launched a centrally supported program in 1975, in Maharashtra. The Migration Tracking System (MTS)

is a website-based application tracking migrant workers' movements, ensuring the coherence of Services towards Integrated Child Development along with their families.

Which initiatives fall under the ICDS?

- Scheme for Anganwadi Activities**:** This initiative is a special beginning of a school and care program. Children aged 0-6 years and pregnant and nursing mothers are the participants in the program. The program delivers six services as a package: supplementary nutrition, non-formal education and pre-school, nutrition education and health education, immunization, health check-up, and referral services. Supplementary nutrition that includes take-home rations (THR) and hot cooked meals and morning snacks is among the supplementary nutrition options that are important for many at-risk families, as it affects nutritional outcomes for children.

- **Under the Pradhan Mantri Matru Vandana Yojana:** Pregnant women and lactating mothers (PW&LM) who meet certain requirements for payment through Direct Benefit Transfer (DBT) Mode during pregnancy and lactation can receive cash assistance of Rs. 5,000 in 3 installments to their bank or postal office account.

- **Pradhan Mantri Matru Vandana Yojana:** It provides cash assistance of Rs. 5,000 in three installments to the bank or post office account of pregnant women and lactating mothers (PW&LM) if the person fulfills certain conditions in payment through Direct Benefit Transfer (DBT) Mode during pregnancy and lactation.

- **Rajiv Gandhi National Crèche Scheme:** It provides childcare services for working mothers to take care of their children, who are between six months and six years old. The hours of facility operation are twenty-six days per month for seven and a half hours per day. Apart from health and sleeping facilities, the children receive an early childcare education component and some supplementary food.

- **Scheme for Adolescent Girls:** It aims to empower and uplift the social situations of 11 to 14-year-old girls who are not in school by providing nutrition, life skills, and home management skills. The program includes the mineral iron, folic acids, and nourishment supplementary feeding, wellbeing screening, and services for referral, including out-of-school females in official school pathways and skills development, teaching them life skills, promoting good diet and health, and other relevant competencies, and various forms of counseling and support in accessing public services.

- **Child Protection Scheme**: It aims to lower children's exposure to risks such as mistreatment, disregard, exploitative behavior, desertion, and parental separation, while also supporting the well-being of children facing difficult circumstances**.**
- **POSHAN Abhiyaan:** The program aims to reduce stunting, undernutrition, anemia, and the incidence of low-birth-weight infants by decreasing malnutrition, undernutrition, and anemia in early childhood. Specific attention is also given to teenage females, expectant mothers, and breastfeeding women.

What are the primary goals of the Integrated Child Development Scheme?

- To enhance the nutritional status and general health of infants to age six.
- To provide an adequate basis for the social, bodily, and mental growth of a healthy kid.
- To decrease the incidence of dropout, malnutrition, diseases, and mortality.
- To coordinate policy and practice across departments to support child development successfully.
- To enable mothers to provide for the child's regular nutritional and medical requirements as necessary.
- Empowering, educating, and supporting adolescent girls (AGs) so they can become empowered independent citizens.

What Hunger-Related Issues Exist in India?

- **Inefficient Public Distribution System (PDS):** Despite all the advancements, India's PDS still has trouble reaching everyone who should be accessing it. Although 67% of the population is included in the National Food Security Act, 90 million qualified people do not receive their legal entitlements through the designated public distribution system.
- **Deprivation and disparities in income:** Despite India's tremendous progress toward eliminating poverty—it has lifted around 24.82 crore people out of various forms of poverty in the last nine years—there are still large economic gaps that prevent many people from having access to enough food.
- **Nutritional Challenges and Dietary Diversity:** In India, Sufficient caloric intake is frequently prioritized over nutritional adequacy when discussing food security.

- **Industrialization and Transforming Nutritional Systems**: India's accelerating urbanism in India is reshaping the country's food systems and dietary habits. A 2022 study conducted by the Tata-Cornell Institute found that more than half (51%) of households in the inner-city slums of Delhi experienced a shortage of food.
- **Gender-Based Nutritional Gap:** The challenges of hunger and malnutrition in India are compounded by inequalities based on gender. Women and girls frequently live with the inequitable distribution of food at the household level, consuming meals that are of lower quality or quantity. They are not only affected by this inequality, but also the additional burden and risk of chronic undernutrition due to their reproductive roles and childcare.
- **Corruption:** Resources meant to reduce hunger may be diverted by corruption.
- **Inefficiency:** Delays and resource waste might result from ineffective implementation.
- **Lack of Awareness:** Many people may be unaware of the initiatives that are offered to the public.

Challenges to Food Security in India:

India's food security faces challenges like malnutrition, poor distribution methods, agricultural industry vulnerabilities, and climate change impacts. Child malnutrition contributes to India's GHI score, with 19.3% wasted and 35.5% stunted. Low care, maternal health, and sanitation standards worsen these issues. Child stunting rates have remained stagnant at 35.5% in 2023, indicating systemic issues in nutrition, health, and knowledge. High child wasting rates indicate acute malnutrition. Food security is impacted by gaps in the Public Distribution System and poor agricultural infrastructure. Climate change increases vulnerability, particularly in rain-fed regions, leading to food shortages. The Pradhan Mantri Matru and POSHAN Abhiyan, Pradhan Mantri Garib Kalyan, and Vandana Yojana India have launched various initiatives to promote food security, but discrepancies exist across regions. The Public Distribution System (PDS) should adopt digitization and transparency to improve subsidy targeting and reduce corruption. (Das and Iram, 2023) India can learn from Bangladesh and Vietnam's successful community-based nutrition initiatives and rural infrastructure improvements, focusing on nutrition-sensitive agricultural and social protection strategies (Nisbett *et al.,* 2017).

Conclusion

With high rates of child stunting and wasting indicating ongoing nutritional deficits, inadequate health systems, and unequal access to resources, food security in India is still a major challenge. Although programs like the Public Distribution System, PMMVY, Mission POSHAN 2.0, and POSHAN Abhiyaan have offered crucial safety nets, their efficacy varies because of issues with governance, poor infrastructure, and regional differences. Through microfinance and Self-Help Groups (SHGs), women's involvement in agriculture, decision-making, and household nutrition can be reinforced. The situation of food security is further complicated by the increasing effects of climate change, increased urbanization, and changing dietary habits. It will be necessary to ensure inclusivity, resilience, and long-term sustainability in the nation's food systems in addition to fortifying current policies in order to achieve sustainable food security and accomplish the Zero Hunger objective under SDG 2, and for unlocking the nation's full human and economic potential.

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Food and Nutrition Security to Mitigate Global Hunger Index apropos India

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Abstract

Hunger and malnutrition remain critical challenges globally, with India ranking 105th out of 127 countries in the Global Hunger Index (GHI) of 2024, classified under the "serious" category. This paradox exists despite India's status as one of the largest producers of food globally. This chapter explores the multidimensional aspects of hunger, including food insecurity, malnutrition, undernourishment, and systemic poverty. It critically examines India's performance across GHI indicators i.e., undernourishment, child stunting, child wasting and under-five mortality—using the latest data from GHI 2024 and NFHS-5 reports. The chapter also delves into structural challenges such as inefficiencies in the Public Distribution System, dietary inadequacies, gender disparities, and underinvestment in maternal-child nutrition. Policy initiatives like POSHAN Abhiyaan, NFSA, PMGKAY, and Mid-Day Meal Scheme are evaluated for their role in addressing nutritional gaps. Importantly, India's Gini Index of 25.5, among the lowest globally, reflects a rare level of economic equality for a nation of its scale. This social equity signals India's strong potential to translate inclusive growth into improved food and nutrition outcomes. Leveraging this advantage through targeted, nutrition-sensitive, and gender-responsive policies is crucial for advancing toward SDG 2: Zero Hunger.

Keywords: Child malnutrition, food security, Gini index, Global Hunger Index (GHI), nutrition security.

1. Introduction

Currently, the world is witnessing an unprecedented hunger crisis affecting millions of children. Across 79 nations, approximately 345 million individuals are experiencing intense food insecurity, with around 50 million teetering on the edge of starvation. Among them, more than 35 million children below the age of 5 are affected by wasting, recognized as the most severe and immediately life-threatening manifestation of malnutrition (Plan International, 2025). The 2024 edition of the State of Food Security and Nutrition in the World report estimates that in 2023, between 713 and 757 million individuals representing 8.9 to 9.4% of the global population experienced hunger. This equates to roughly 1 in every 11 people globally, and 1 in every 5 across the African continent (FAO, IFAD, UNICEF, WFP & WHO, 2024). Besides hunger, the report points out that approximately 2.33 billion people were impacted by moderate to severe levels of food insecurity, with 0.9 billion experiencing acute food insecurity. In addition, over 3.1 billion people were not able to access a healthy diet (United Nations, 2025). Notwithstanding global food production being adequate to feed the entire population, around 733 million individuals still suffer from hunger. Hunger is associated with nearly half of all child deaths worldwide. Globally, an estimated 148 million children are affected by stunting (Action AgainHunger, 2025a).

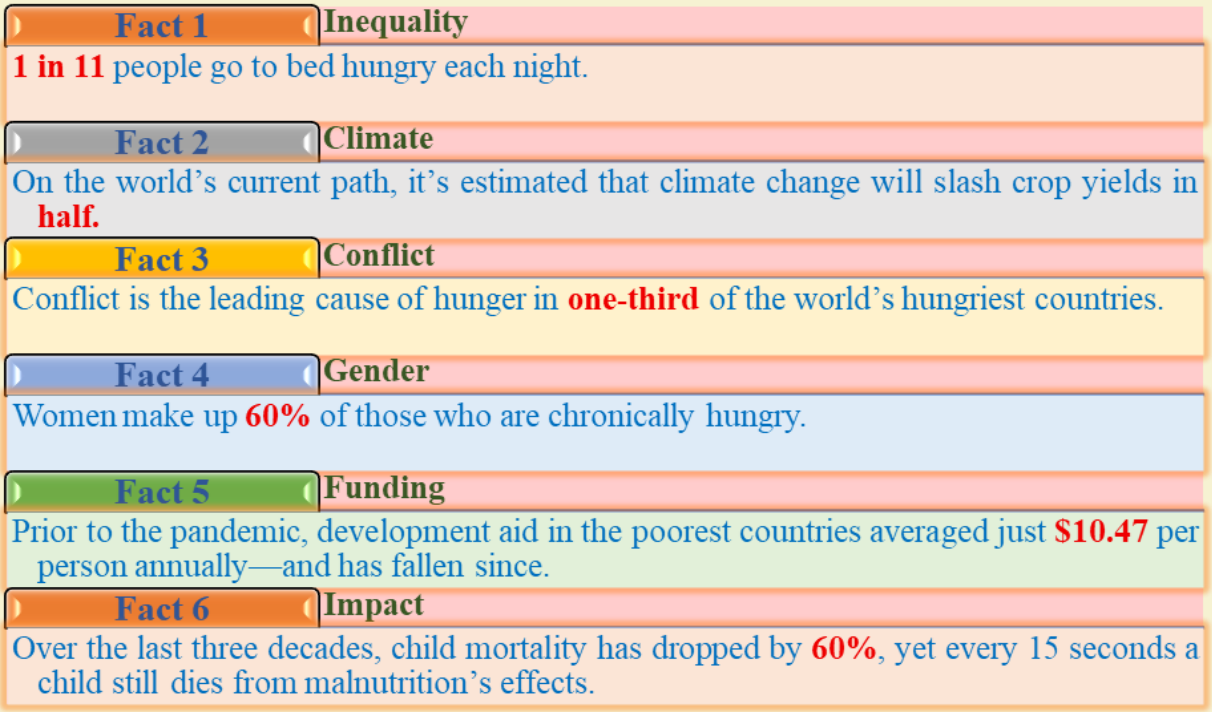


Fig. 1. The prominent 6 facts about global hunger (Source: Action Against Hunger, 2025b)

India, despite being the world's fourth-largest and fastest-growing major economy (PIB, 2025a) and a major producer of cereals, pulses, fruits, and vegetables, has consistently performed poorly in the Global Hunger Index (GHI). As of the 2024 GHI, India ranked 105th among 127 countries, categorized under the "serious" hunger level with a score of 27.3 (GHI, 2024a). This marks a significant decline in global standing compared to its 2020 rank of 94th (The Hindu, 2020), raising critical concerns about the country's ability to ensure basic food and nutritional security for its population. The downward trajectory of India's GHI ranking is largely influenced by the persistent prevalence of child undernutrition. As per the National Family Health Survey-5 (NFHS-5), around 35.5% of Indian children under the age of 5 are stunted, i.e., low height as per age, 19.3% are wasted, i.e., low weight as per height, and 32.1% are underweight (MoHFW, 2021). Wasting, in particular, which reflects acute malnutrition, continues to be alarmingly high in India, contributing heavily to the poor GHI performance. India's struggle with hunger and malnutrition is paradoxical in the context of its overflowing food grain stocks and advanced agricultural infrastructure. The structural challenges lie in the distribution system, income disparities, lack of dietary diversity, and limited availability and utilization of healthcare and sanitation facilities. The Public Distribution System (PDS), while effective in many states, suffers from leakages, exclusion errors, and limited dietary focus—primarily supplying rice and wheat, with little emphasis on protein- and micronutrient-rich foods. Although some improvements have been recorded in stunting rates over the last decade, the pace of change remains slow and uneven across states and socio-economic groups. India is one of 42 nations classified under the "serious" category of hunger, along with countries like Pakistan and Afghanistan. In contrast, neighboring South Asian countries such as Nepal, Bangladesh, and Sri Lanka have achieved relatively better Global Hunger Index scores, placing them in the "moderate" category (The Hindu, 2024). India's position in the GHI, therefore, is not merely a numerical rank but a reflection of the deeper crisis in human development. Addressing this requires a multifaceted strategy—integrating agriculture, health, education, gender, and governance reforms to ensure not just food availability but also accessibility, affordability, and adequate nutrition.

1.1. Objectives of the chapter

The primary objective of this chapter is to explore and critically analyze the interrelationship among food security, nutrition security, and the Global Hunger Index (GHI) in the context of India. Given India's paradoxical status as a leading food producer yet a country grappling with

high levels of hunger and malnutrition, this chapter seeks to furnish an omnibus understanding of the underlying factors, policy interventions, and pathways toward sustainable solutions.

2. What hunger actually is?

According to the Food and Agriculture Organization (FAO), "Hunger is an uncomfortable or painful physical sensation caused by insufficient consumption of dietary energy. It becomes chronic when the person does not consume a sufficient amount of calories (dietary energy) regularly to lead a normal, active, and healthy life." Hunger is often equated with chronic undernourishment and is assessed through the prevalence of undernourishment (FAO, IFAD, UNICEF, WFP & WHO, 2024; Concern Worldwide, 2024).

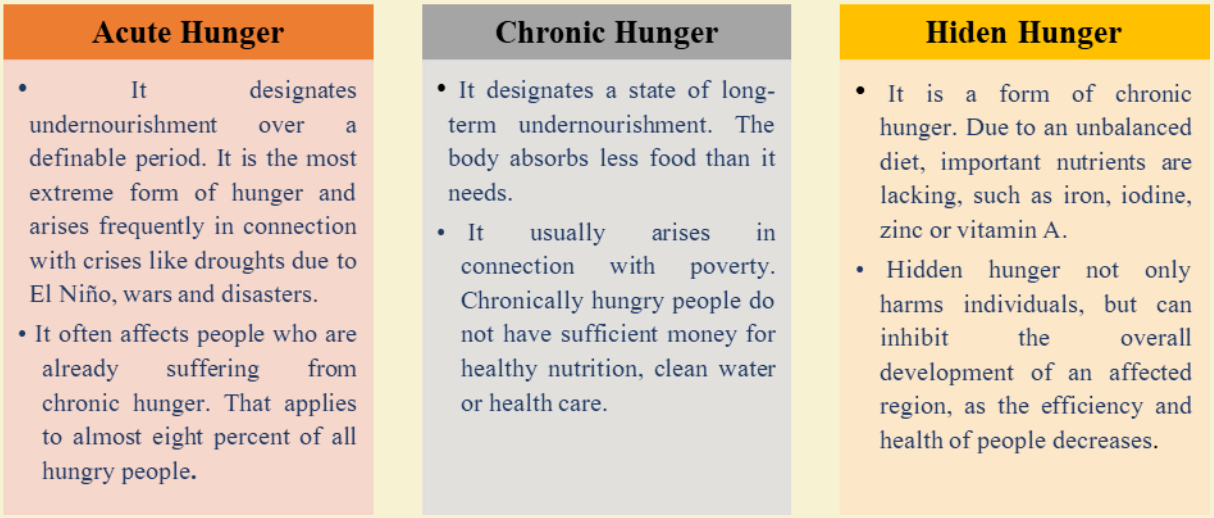


Fig. 2. Difference among three types of hunger (Source: Welthungerhilfe, 2025a)

Contextual terminologies used to describe hunger

2.1. Food insecurity: Food insecurity arises when individuals do not consistently have access to plenteous, nutritious, and safe food required for proper growth, development, and leading an active, healthy life. The situation can be caused by either the scarcity of food or inadequate means to acquire it. The intensity of food insecurity can range from mild to moderate or severe (United Nations, 2025). Broadly, food insecurity is categorized into two main categories: [i] Chronic food insecurity, and [ii] Transitory food insecurity (FAO, 2008).

Table 1: The duration of food insecurity

	Chronic food insecurity 	Transitory food insecurity 
Nature of the condition	A condition that persists over a long duration.	A short-lived and temporary situation.
Condition arises when	Individuals consistently fail to meet their essential dietary needs over an extended period of time.	A sudden decline occurs in the capacity to either produce or access sufficient food to sustain proper nutritional levels.
Root causes include	Prolonged poverty, insufficient assets, and limited access to financial or productive resources.	Arises due to abrupt disruptions and variability in food supply and access—this includes annual changes in domestic agricultural output, food pricing, and household earnings.
Addressed through	Addressed through long-term strategies similar to those used for poverty alleviation—such as improving education or providing access to productive assets like credit. In some cases, ensuring direct food access is essential to enhance individuals' productivity.	This form of food insecurity is often unexpected, making it harder to predict and manage. Tackling it effectively requires specific interventions and preparedness measures, including early warning systems and social safety net initiatives.

2.2. Malnutrition: Malnutrition arises due to imbalances, deficiencies, or excesses in the intake of macro- and/or micronutrients. It can result from food insecurity, but may also stem from factors unrelated to food, including:

i) poor caregiving practices for children,

ii) limited access to healthcare services, and

iii) unsanitary or harmful living conditions.

Although poverty is a well-known driver of hunger, the absence of sufficient and appropriate nutrition also plays a fundamental role in perpetuating poverty.

2.2.1. Acute malnutrition: Wasting or having a weight significantly lower than expected for one's height occurs as a result of nutritional deficiencies, which may be caused by inadequate dietary intake or impaired nutrient absorption. Children experiencing acute malnutrition are typically classified into below two categories.

- **Moderate acute malnutrition** is identified when an individual's weight relative to their height falls below 80% of the standard reference range.
- **Severe acute malnutrition** is diagnosed when an individual's weight falls below 70% of the median weight-for-height standard.

2.2.2. Chronic malnutrition: It is commonly referred to as stunting, occurs when inadequate nutrition persists over time, resulting in a height-for-age measurement that is at least two standard deviations (2SD) below the median.

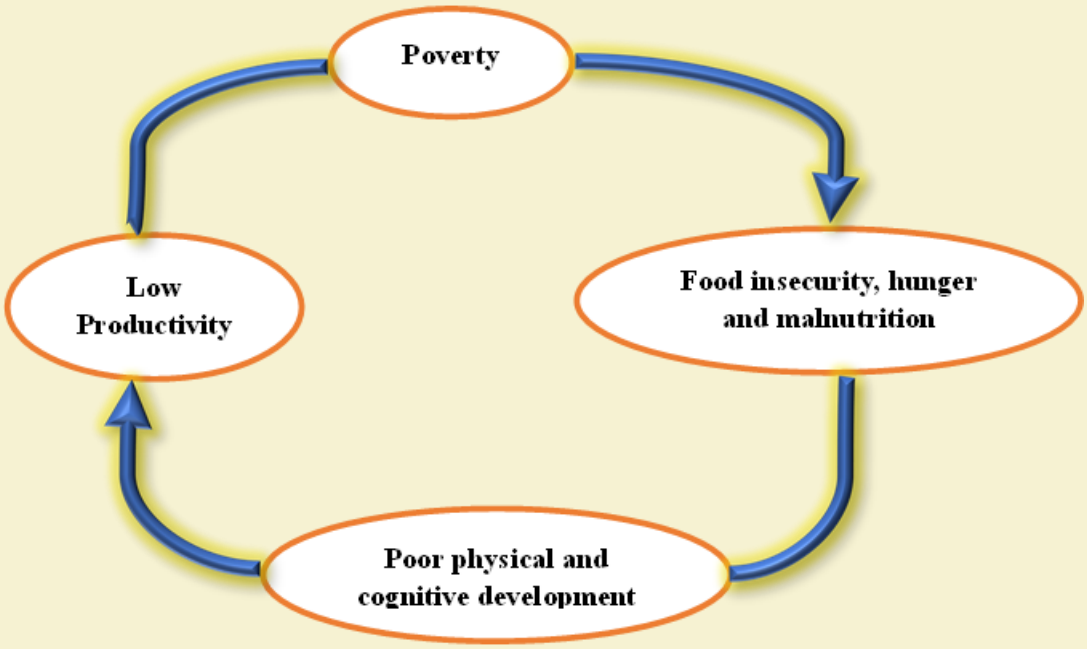


Fig. 3. Food insecurity, undernutrition, and poverty are closely connected and influence one another (FAO, 2008)

2.3. Undernutrition: It occurs when an individual fails to consume sufficient energy and essential nutrients to sustain regular bodily functions, growth, and development. This condition may be general, such as inadequate overall food intake, or more specific, involving deficiencies in particular micronutrients. (Concern Worldwide, 2024).

2.4. Poverty: According to the Organization for Economic Co-operation and Development (OECD), "Poverty encompasses different dimensions of deprivation that relate to human

capabilities including consumption and food security, health, education, rights, voice, security, dignity and decent work" (FAO, 2008).

2.5. Famine: The term "famine" is frequently employed—sometimes inaccurately—for emotional or rhetorical impact to describe food crises of different scales. However, there are specific and measurable criteria that must be met for an official famine declaration. A famine is recognized when:

- ✓ Around 20% of the population faces severe shortages of food,
- ✓ About 30% or more of children under the age of 5 years old are experiencing acute malnutrition, and
- ✓ The mortality rate has risen significantly, with at least 2 deaths per 10,000 people every day, or 4 deaths per 10,000 children per day (Concern Worldwide, 2024).

2.6. Food security: "Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices" (United Nations, 1975). As per FAO, food security is "ensuring that all people at all times have both physical and economic access to the basic food that they need" (FAO, 1983). As defined by the USDA (2009), food security encompasses reliable access to sufficient, nutritious, and safe food, along with the ability to obtain acceptable food through socially acceptable means—without relying on emergency food sources, scavenging, theft, or other survival tactics. It also involves proper utilization, which depends on knowledge of nutrition and caregiving, as well as access to clean water and adequate sanitation.

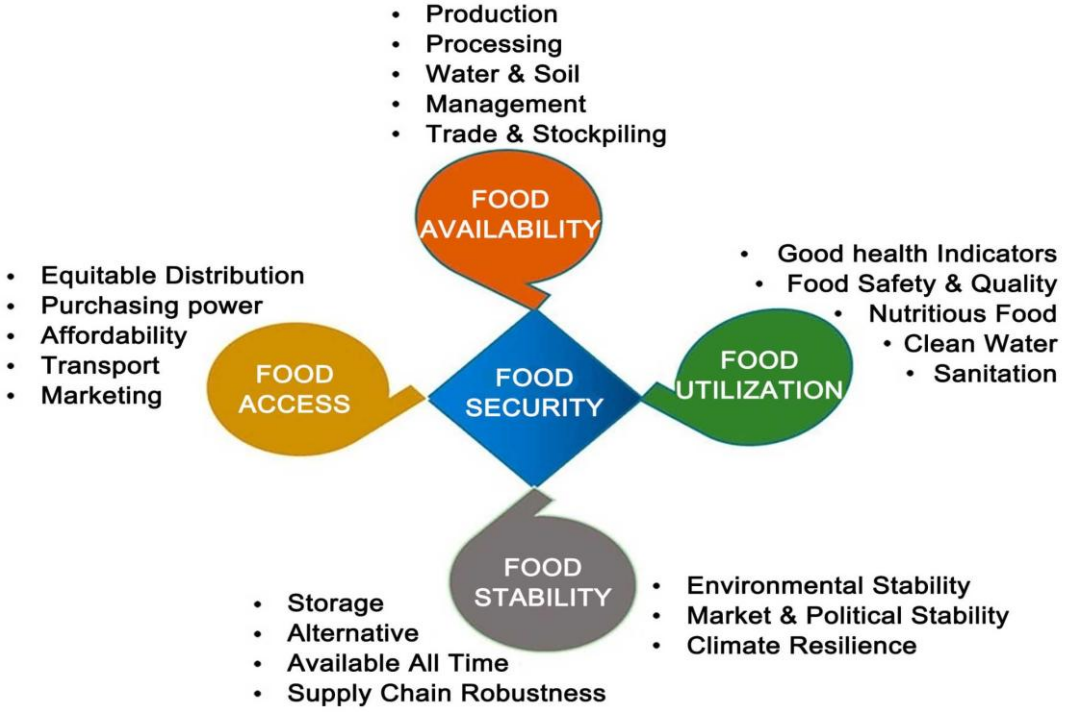


Fig. 4. Four main dimensions of food security (Source: FAO, 2008; Owasa & Fall, 2024)

2.7. Nutrition security: According to the USDA, nutrition security is defined as "consistent and equitable access to healthy, safe, and affordable foods that promote optimal health and well-being." While its definition closely aligns with that of food security, it further emphasizes aspects such as dietary quality, equitable health access, and the availability as well as affordability of foods that support overall health and well-being. Food and nutrition security remains among the most pressing global challenges. By 2030, the aim is to ensure that everyone has consistent access to adequate food and can follow a healthy and sustainable diet (Jones *et al.,* 2023; USDA, 2024).

Fig.5. Nutrition security (Source: USDA, 2024)

3. Understanding the Global Hunger Index (GHI)

3.1. Definition and purpose of GHI

The Global Hunger Index (GHI) serves as a comprehensive tool for monitoring and assessing hunger across global, regional, and national scales, capturing its various dimensions over time. It is a peer-reviewed publication released yearly by Welthungerhilfe, Concern Worldwide, and the Institute for International Law of Peace and Armed Conflict (IFHV) (Table 2). GHI 2024 is the 19th edition of the report. The purpose of the report is to enhance awareness, and deeper understanding of the global fight against hunger, offering a basis for comparing hunger levels across different countries and regions. The GHI also highlights the parts of the world most severely affected by hunger, emphasizing where intensified action is most urgently needed to combat it (GHI, 2024a).

Table 2. Organizations/ institutions responsible for publishing the annual GHI report

WELT HUNGER HILFE	Welthungerhilfe, founded in 1962 as part of the "Freedom from Hunger Campaign," is among Germany's largest independent aid organizations. It operates without political or religious affiliation (Welthungerhilfe, 2025b).
CONCERN worldwide	Concern Worldwide is a global humanitarian organization that partners with the world's most vulnerable populations to reduce poverty and ease human suffering, particularly in the most disadvantaged regions (Acted, 2025).
IFHV	The Institute for International Law of Peace and Armed Conflict (IFHV) is recognized as one of Europe's prominent academic centers specializing in research on several humanitarian crises (IFHV, 2025).

3.2. Methodology

A country's GHI score is determined using a formula that integrates 4 key indicators (Fig. 6), which collectively reflect the complex and multifaceted nature of hunger: undernourishment, child stunting, child wasting, and child mortality.

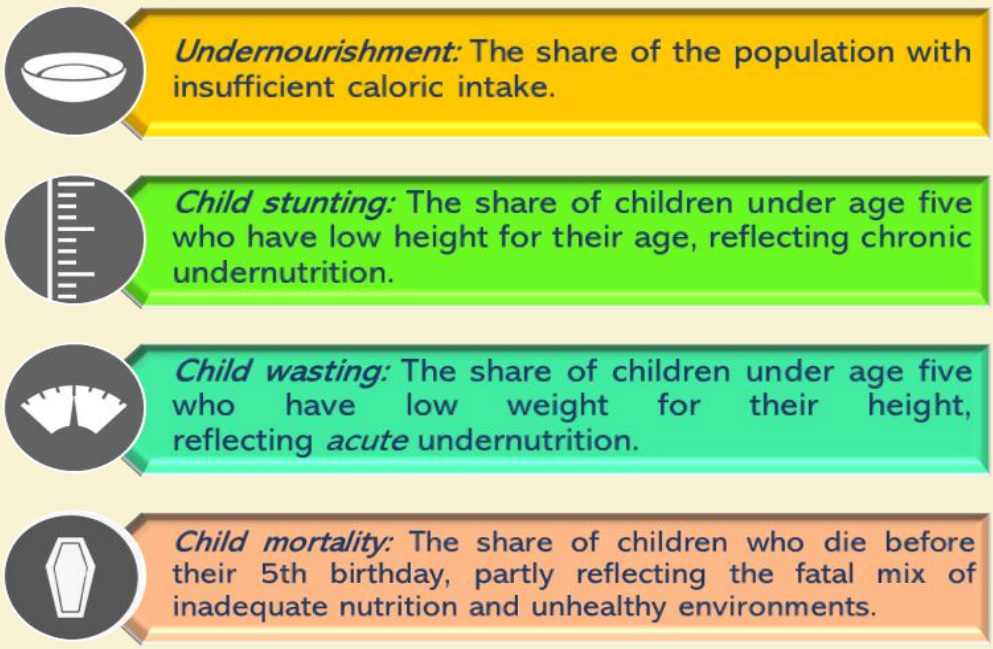


Fig. 6. The four indicators of Global Hunger Index (GHI, 2024a)

Table 3. How do the four indicators of the GHI reflect the various dimensions of hunger? (GHI, 2024a)

Undernourishment	✚ Assesses insufficient access to food, serving as a crucial metric for identifying hunger. ✚ Applies to the whole population, encompassing both adults and children. ✚ Works as a primary indicator for monitoring global hunger-related goals, such as SDG-2: Sustainable Development Goal 2 (Zero Hunger).
Child stunting	✚ Extend beyond mere calorie intake to account for diet quality and the body's ability to effectively utilize nutrients. ✚ Highlight the heightened susceptibility of children to nutrient deficiencies. ✚ Capture disparities in how food is distributed among household members. ✚ Function as key nutritional metrics for evaluating progress toward SDG 2 (Zero Hunger).
Child wasting	
Child mortality	✚ Emphasizes that death represents the most severe outcome of hunger, with children being the most at risk.

	✚ Enhances the GHI's capacity to indicate shortages in vital vitamins and minerals. ✚ Recognizes that stunting and wasting alone do not fully represent the fatal risks associated with undernutrition.

3.2.1 Three-step process for GHI score calculation

GHI score for each country is calculated by following the below 3 steps (Fig. 7).

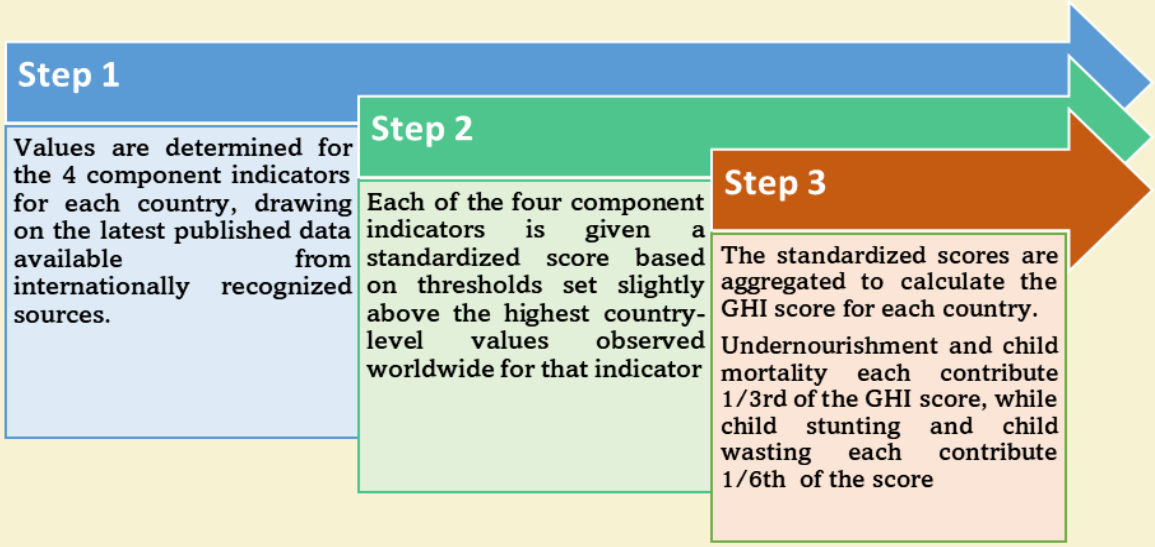


Fig. 7. Three-step process for GHI score calculation (Source: GHI, 2024a)

<u>Step 2</u>: Formula for standardization of component indicators (Wiesmann *et al.*, 2015):

- Value of the standardized undernourishment $= \frac{PU}{80} \times 100$
- Value of the standardized child stunting $= \frac{CS}{70} \times 100$
- Value of the standardized child wasting $= \frac{CW}{30} \times 100$
- Value of the standardized child mortality $= \frac{CM}{35} \times 100$

Where,

- PU = Prevalance of undernourishment
- CS = Rate of child stunting
- CW = Rate of child wasting
- CM = Rate of child mortality

• **Composition of GHI scores:** Before Wiesmann et al. revised the Global Hunger Index (GHI) methodology in 2015, the calculation of the GHI was based on three core indicators (undernourishment, child undernutrition and child mortality). These earlier indicators were selected to reflect different dimensions of hunger but lacked some of the refinement and robustness. In Wiesmann et al. (2015), the child underweight indicator was substituted with two separate measures: child stunting and child wasting. The one-third weighting previously assigned to the undernutrition component was evenly divided between these two indicators.

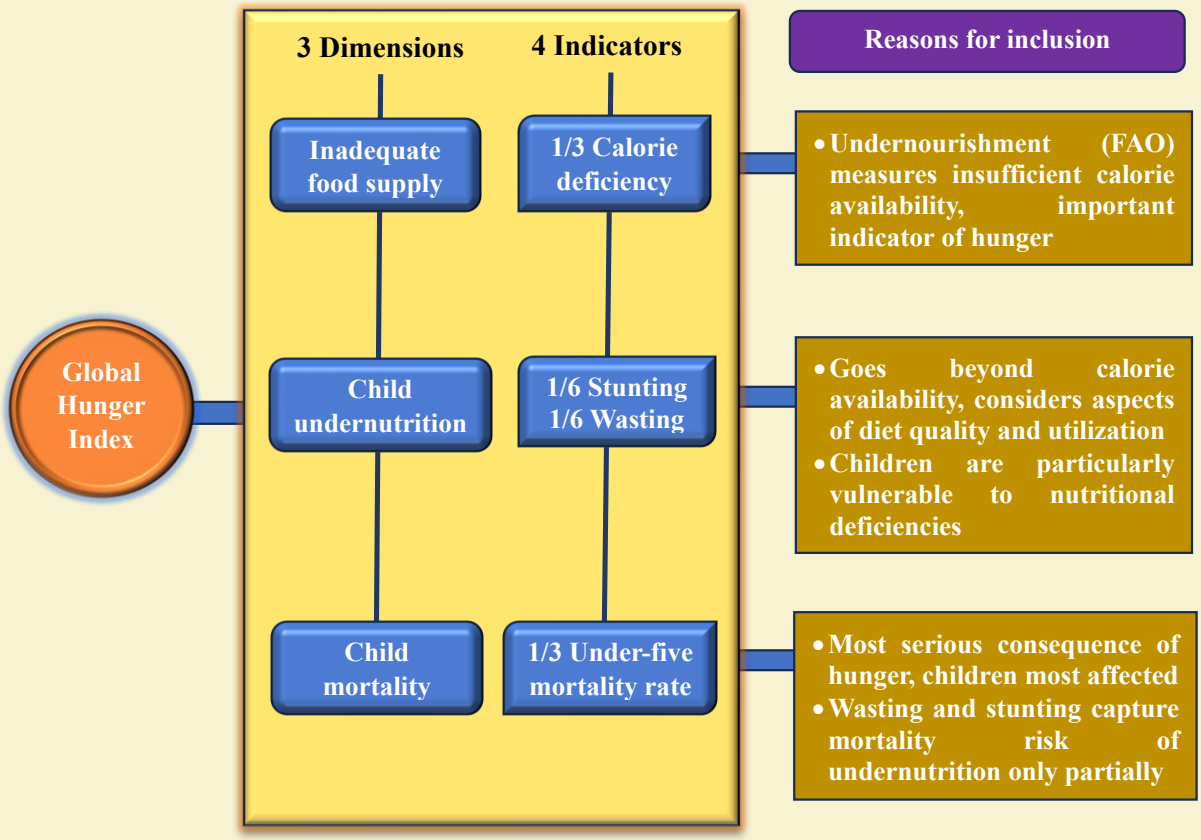


Fig. 8. GHI Composition (Source: Wiesmann *et al.*, 2015)

Step 3: Formula for GHI score calculation

- $$GHI = \frac{1}{3} \times \left(\frac{PU}{80} \times 100\right) + \frac{1}{6} \times \left(\frac{CS}{70} \times 100\right) + \frac{1}{6} \times \left(\frac{CW}{30} \times 100\right) + \frac{1}{3} \times \left(\frac{CM}{35} \times 100\right)$$

Where,

GHI= Global Hunger Index

• **GHI severity scale:** The GHI score is measured on a scale that ranges from 0 - 100, in which 0 represents the best possible outcome, i.e., no hunger, and 100 represents the worst. In reality, neither extreme is ever fully reached. A score of 100 would indicate that a country's rates for all four indicators of GHI either match or exceed thresholds set just above the highest levels recorded globally in recent decades. Conversely, a score of 0 would reflect a situation where no one in the population is undernourished, no children under 5 are wasted or stunted, and no child dies before reaching age five. Each of the country's GHI scores is assigned a severity level, ranging from low to extremely alarming (Fig. 9). The GHI 2024 was conducted for 127 countries, out of which 51, 37, 36, 6, and 0 countries fell under the low, moderate, serious, alarming, and extremely alarming categories, respectively (GHI, 2024a).

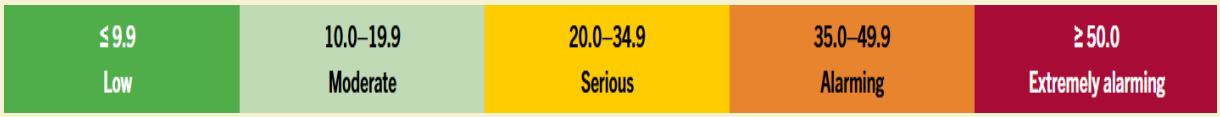


Fig. 9. GHI Severity Scale (100-point scale) (Source: GHI, 2024)

4. India's performance in GHI 2024

India's GHI score for 2024 stands at 27.3, placing it in the "serious" category alongside 41 other countries, including Afghanistan and Pakistan, as per the GHI Severity Scale of Hunger. This marks a modest improvement from its 2016 score of 29.3—also classified as serious—and shows significant progress when compared to its 2000 and 2008 scores of 38.4 and 35.2, respectively, both of which were categorized as alarming (Fig. 10). In the 2024 GHI report, India ranks 105th out of 127 countries, an improvement from its 111th position in 2023. With a population of 140 crore, India accounts for roughly 25% of the world's undernourished people and is home to over 190 million individuals experiencing hunger (ETV Bharat, 2024).

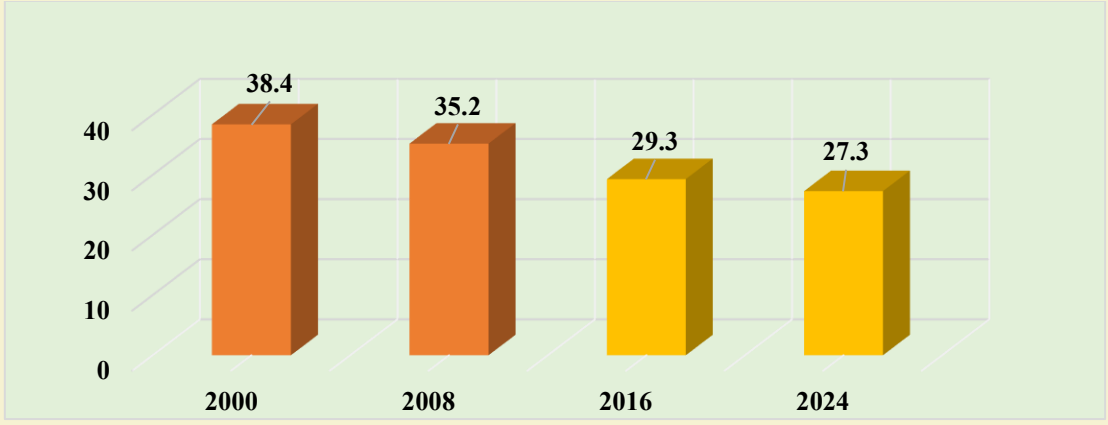


Fig. 10. GHI score trend for India (2000-2024) (Source: GHI, 2024a)

India reports the highest rate of child wasting in the GHI 2024, at 18.7 percent. The child stunting rate stands at 35.5%, placing the country 14th in global rankings. The prevalence of undernourishment is 13.7%, and the under-five mortality rate is 2.9%. Since 2000, India has made notable progress in reducing child mortality. However, it continues to record the highest level of child wasting and one of the highest rates of child stunting. Although the stunting rate has dropped significantly since 2000, both indicators of child undernutrition remain critically high from a public health perspective. Undernourishment has generally declined since 2000, yet a slight upward trend has been observed in recent years. Child undernutrition in India is closely linked to the poor nutritional condition of mothers, highlighting the urgent need to improve maternal health and nutrition (GHI, 2024a).

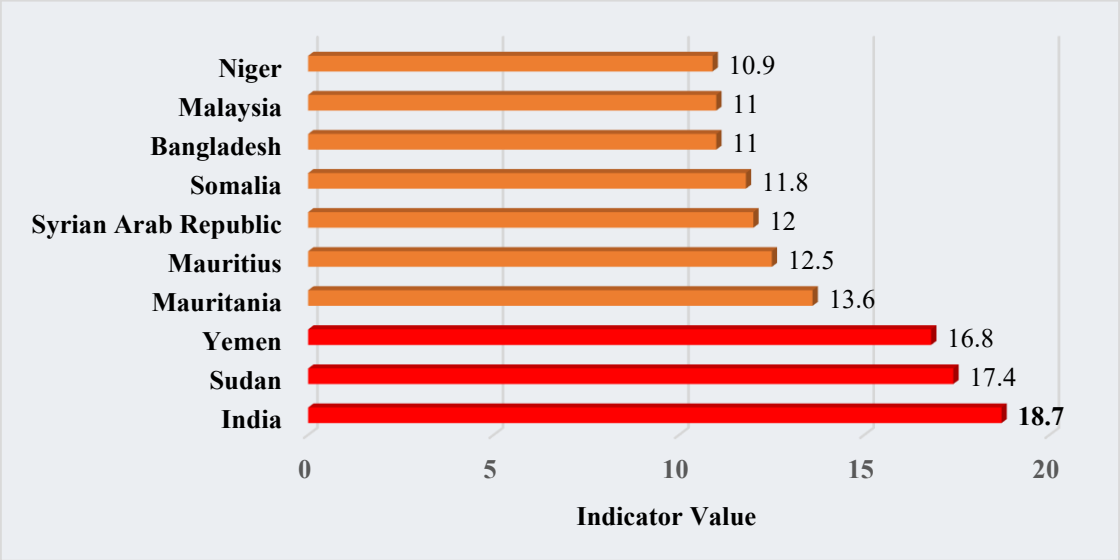


Fig. 11. Child wasting percentage of the countries with the highest indicator value (2019-2023) (Source: GHI, 2024b)

So, it is evident that child wasting is a major concern for increasing the GHI index score of India. Choudhary et al. (2024) examined the occurrence of wasting among children below the age of 5 and the contributing factors. Their study revealed a significant burden of wasting in India, with considerable variation across states and the highest prevalence occurring within the first six months of life. Key determinants included socioeconomic status, maternal nutritional health, and low birth weight (LBW), indicating that wasting in India stems from a range of interrelated factors. These findings underscore the need for increased focus on preventive strategies beginning in the preconception and antenatal periods, along with continuous care for LBW infants and those showing signs of wasting early in life. National initiatives such as Poshan Abhiyaan and programs like the Integrated Child Development Services (ICDS) bear

the potential to positively impact these contributing factors—provided they are effectively implemented and reach all children in need.

4.1. Status of world GHI

The Global Hunger Index score for the world in 2024 is 18.3, which falls within the moderate range and reflects only a slight decrease from the 2016 score of 18.8. In 42 countries, hunger remains at alarming levels, putting the achievement of Zero Hunger by 2030 out of reach. If current trends persist, global hunger levels may not decline to low levels until the year 2160. Worldwide, approximately 733 million individuals experience hunger daily because they lack adequate access to sufficient food, and around 2800 million people are unable to afford a nutritious diet. Belarus, Bosnia and Herzegovina, Chile, China, along with several other countries, are ranked highly on the Global Hunger Index (GHI) with “low” hunger levels (≤9.9). It means they have strong food security and low rates of undernourishment and child mortality. Several African countries fall into the "alarming" category on the GHI scale, with ongoing conflicts in regions like Gaza and Sudan contributing to severe food crises. The report draws attention to the interconnection between gender inequality, hunger, and climate change. It emphasizes that gender dynamics are deeply embedded within climate and food security issues—yet are often overlooked in related policies and interventions. Women and girls tend to be the most affected by malnutrition and food insecurity and are also more susceptible to the consequences of extreme weather events and disasters related to climate (GHI, 2024b; The Hindu, 2024). The GHI score of India is far more than the world average. That means India is lagging to combat hunger crisis than many countries of world under consideration. Even India has more GHI index score than the average of South Asia Countries. As per the regional Global Hunger Index, the score for South Asia is 26.2 in 2024 slightly improved than 2016 which was 27.7. South Asia is home to approximately 281 million undernourished individuals, representing nearly 40% of the world’s total undernourished population. If the 2024 GHI score of all the neighbouring countries of India in South, East and Southeast Asia are considered, most of countries like Bangladesh, Myanmar, Nepal, Sri Lanka, and China are performing better than India (Table 4). The countries have a “moderate” or “low” level of hunger unlike India.

Table 4: Better performing neighbouring countries of India in South, East and Southeast Asia for GHI 2024

Country	GHI Score	Hunger Level
China	<5	*Low*
Sri Lanka	11.3	*Moderate*
Nepal	14.7	*Moderate*
Myanmar	15.7	*Moderate*
Bangladesh	19.4	*Moderate*

4.2. National Family Health Survey-5 (NFHS-5)

The 2019–21 National Family Health Survey i.e., NFHS-5, the 5th and in the most recent NFHS series, offers comprehensive data on population, nutrition, and health across India, including all states and union territories. Similar to NFHS-4, it also includes district level estimates for several key indicators. All the 5 rounds of the NFHS have been carried out under the leadership of the Ministry of Health and Family Welfare (MoHFW), Government of India. As reported by the NFHS-5 (NFHS, 2025), 35.5% of children below 5 years of age in India are stunted (indicating low height for age), 19.3% are wasted (indicating low weight for height), 32.1% are classified as underweight, and 49.7% of children who die before they attain their age 5. As reported in NFHS-4 (2015–16), among Indian children (age <5), 38.4% were stunted, 21.0% were wasted, 35.8% were underweight, and the under-five mortality rate stood at 41.9%. So, it is evident that within the gap of 5 years, in the NFHS-5, the child stunting, wasting and underweight problem below the age of 5 have been improved up to some extent (MoHFW, 2021). NFHS-5 reported that Meghalaya (47%) has the highest rate of child stunting of below 5 years age followed by Bihar (43%) and Gujarat (39%). Maharashtra (10.9%) has the highest rate of child wasting of below 5 years age followed by Gujarat (10.6%) and Assam (9.1%) (PRS India, 2025).

5. Challenges behind prevalence of hunger in India

5.1. Inefficiencies in the Public Distribution System (PDS): Although India's PDS has seen progress over time, it continues to face significant barriers in effectively reaching all eligible recipients.

- The National Food Security Act currently extends coverage to only 67% of the population that are 75% in the rural areas and 50% in the urban settings.
- Over 90 million people who qualify for support have been left out of the legal entitlements provided under the Targeted Public Distribution System (TPDS) (Down To Earth, 2022).

5.2. Income Inequality and Poverty: Despite notable progress in poverty alleviation—with 24.82 crore people moving out of multidimensional poverty over the past nine years—substantial income inequality remains a challenge, continuing to impact access to adequate food (PIB, 2024).

5.3. Nutritional Challenges and Dietary Diversity: In India, food security efforts frequently emphasize meeting calorie requirements, while the importance of ensuring adequate nutritional quality is often overlooked.

5.4. Urbanization and Changing Food Systems: India's fast-paced urbanization is reshaping food systems and altering dietary habits and consumption trends. It changes diets, lifestyles, and food systems. It encourages sedentary behaviour and makes inexpensive, highly processed foods and drinks more accessible. According to a 2022 Tata-Cornell Institute study, 51% of Delhi's urban slum residents were food insecure (Agarwal *et al.,* 2016).

5.5. Gender-Based Nutritional Gap: Gender disparities significantly contribute to the persistence of hunger and malnutrition in India, with women and girls often experiencing greater nutritional disadvantages. Within households, women and girls frequently experience unequal access to food, consuming meals that are of lesser quality or in fewer quantity. Their susceptibility to chronic undernutrition is increased by this injustice as well as the demands of motherhood and child care. In many nations, hunger and the threats posed by climate change to food systems coexist alongside gender inequity. India has a gender inequality index score of 0.437 and the risk to food system from climate change score of 0.606 (GHI, 2024b).

5.6. Undernourished Mothers: A big proportion of Indian women suffer from anaemia, and women from low-income backgrounds who are undernourished often give birth to malnourished infants. As per the NFHS-5, the prevalence of anaemia is alarmingly high—

affecting 57% of women aged 15–49 years, 52.2% of pregnant women, and 59.1% of adolescent girls.

5.7. Low Education Level and Socio-economic Status: The children who born to mothers having no formal education and those belonging to the lowest wealth quintile are significantly more likely to be undernourished.

5.8. Vulnerable Sections: The children belonging to the Other Backward Classes (OBC) exhibit the highest rate of Minimum Dietary Diversity Failure at 79%, followed closely by those from Scheduled Castes at 77.2%, and Scheduled Tribes at 76%.

6. Indian Government Initiatives to Address Hunger and Food Security

6.1 Eat Right India Movement: It is an initiative by FSSAI designed to overhaul India's food system to provide healthy, safe, and sustainable food for all citizens. With the slogan "Sahi Bhojan, Behtar Jeevan," it aligns with the National Health Policy 2017 by emphasizing preventive as well as promotive healthcare. The movement employs a balanced mix of regulatory measures, collaboration, capacity building, and empowerment strategies to ensure that food choices benefit both people and the environment (FSSAI, 2020).

6.2 POSHAN Abhiyaan: The Government of India launched the POSHAN Abhiyaan (National Nutrition Mission) on March 8, 2018, as a nationwide initiative to improve nutritional outcomes, to guarantee a supply of nutrients through domestically grown, organic fruits and vegetables while also maintaining the health of the soil. Swasth Bharat Preraks will be placed in every district as part of the Abhiyaan to facilitate coordination with local authorities and enable the Abhiyaan to be carried out quickly and effectively throughout the nation. Swasth Bharat Preraks would serve as a driving force behind expediting the Abhiyaan's implementation (PIB, 2023).

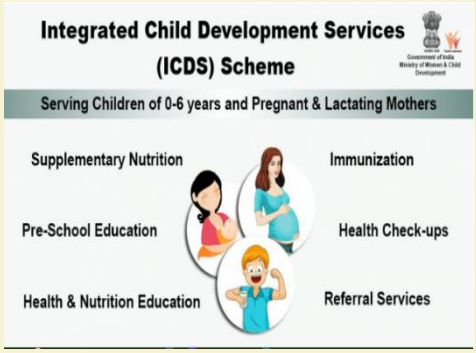
6.3 Mid-Day Meal Scheme (PM POSHAN): The Government of India approved the centrally sponsored Pradhan Mantri Poshan Shakti Nirman (PM POSHAN) scheme, formerly known as the Mid-Day Meal Scheme in September 2021. This flagship initiative seeks to provide one hot cooked meal per day to the children studying in Government and Government-aided schools, Special Training Centres (STCs), as well as Maqtabs, and Madarsas backed by the Sarva Shiksha Abhiyan (SSA), for the period 2021–22 to 2025–26. As per data from 2021–22, the scheme benefits approximately 11.80 crore children enrolled in 11.20 lakh schools across the country. It is recognized as the world's largest school feeding programme, targeting students from Classes 1 to 8 in government schools (IBEF, 2025).

The primary objective of PM POSHAN is to improve school enrolment, retention, and attendance, while simultaneously addressing issues of classroom hunger and malnutrition. Under the terms of the National Food Security Act (NFSA-2013), the program has evolved from a welfare program to a legal entitlement for all primary and upper primary school students.

6.4 Pradhan Mantri Matru Vandana Yojana: This maternity benefit scheme has been operational across all districts of India since January 1, 2017. It is a centrally sponsored program administered by the Ministry of Women and Child Development. Under this scheme, financial assistance is directly transferred to the bank accounts of pregnant women to help meet their increased nutritional necessities and to partially offset income loss during pregnancy (DWCD, 2025).

6.5 National Food Security Act, (NFSA) 2013: The implementation of the National Food Security Act (NFSA), 2013 on July 5, 2013, marked a significant shift from a welfare-based model to a rights-based approach to food security. It provides a legal entitlement to subsidized foodgrains for up to 75% of the rural population and 50% of the urban population by the Targeted Public Distribution System (TPDS). As a progressive step toward women's empowerment, the Act mandates that the eldest woman in the household, aged 18 years or more, shall be recognized as the head of the family for the issuance of ration cards (NFSP, 2025).

6.6 Integrated Child Development Scheme (ICDS): It is a special early childhood care and development programme. Children between the ages of 0 and 6 as well as mothers who are pregnant or breastfeeding are the beneficiaries of the program. Supplementary nutrition, immunization, pre-school non-formal education, health check-up, nutrition and health education, and referral services are the six services it offers as a package.



6.7 Mission Indradhanush (Mission Rainbow): The initiative was introduced to ensure complete immunization of over 89 lakh children who had either not received any vaccines or were only partially immunized under the Universal Immunization Programme (UIP). It covers 12 vaccine-preventable diseases (VPDs), including whooping cough, diphtheria, polio, tetanus, pneumonia, tuberculosis, Japanese encephalitis (JE), hepatitis B, meningitis, rotavirus, Haemophilus influenzae type B infections, measles-rubella (MR), and pneumococcal disease (PCV). Mission Indradhanush was also designated as one of the flagship programmes under both the Gram Swaraj Abhiyan and the Extended Gram Swaraj Abhiyan (NHM, 2025).

6.8 Pradhan Mantri Garib Kalyan Anna Yojana: As part of the Atmanirbhar Bharat initiative, PM-GKAY was launched for providing free food grains to migrant workers and economically vulnerable populations. Under this scheme, the Central Government has extended the provision of free food grains to around 81.35 crore of beneficiaries, including households under the Priority Households (PHH), and Antyodaya Anna Yojana (AAY). This extension will remain in effect for 5 years starting from January 1, 2024. Eligible beneficiaries will continue to receive their entitled quantity—35 kg of food grains per AAY household in each month and 5 kg per PHH household per month (PIB Delhi, 2023).

7. Ways forward

7.1 PDS Enhancement: Strengthen and modernize the Public Distribution System to improve its transparency, effectiveness, and access to affordable, nutritious food for underprivileged communities.

7.2 Social Audit and Awareness: Conduct social audits of the Mid-Day Meal Scheme across all districts with active participation from local authorities. Strengthen monitoring mechanisms using digital tools and promote community-based nutrition education initiatives in regional languages, emphasizing balanced diets for women and children.

7.3 Complementing With SDGs: The Sustainable Development Goals, especially SDG 2 (Zero Hunger) and SDG 12 (Responsible Consumption and Production), focus on the importance of adopting sustainable consumption patterns.

7.4 Investment in Agriculture: Adopting a comprehensive food systems strategy that encourages the production of diverse and nutrient-rich crops, such as millets, is essential. Tackling food loss remains a priority, and enhancing storage facilities—including warehouses and cold chains—can significantly minimize post-harvest wastage.

7.5 Health Investments: Emphasis should be given on the child and maternal health through sanitation, better water, and hygiene practices.

Fig. 12. The way forward

Effective policymaking must acknowledge the interlinked nature of gender, climate change, and nutrition, as these elements play an instrumental role in shaping public health outcomes, promoting social justice, and advancing sustainable development. India ranks not only as the world's fourth-largest economy but also as one of the most equitable societies globally. As per the World Bank, India's Gini Index is 25.5—placing it as the fourth most equal nation

worldwide, following the Slovak Republic, Slovenia, and Belarus. This is a notable accomplishment given India's vast population and diversity. The country's index is significantly lower than China's 35.7 and markedly below the United States' 41.8. India also surpasses all G7 and G20 nations in income equality, many of which are categorized as developed economies. This suggests that the benefits of India's economic growth are more widely distributed. This outcome stems from sustained policy efforts aimed at poverty alleviation, expanding financial inclusion, and delivering targeted welfare to the most vulnerable sections of society (World Bank, 2025; PIB, 2025b). It indicates a strong foundation for improving its Global Hunger Index (GHI) score. As economic gains are distributed more equitably and welfare schemes reach the underserved, the country is well-positioned to reduce undernourishment, child malnutrition, and mortality- the key GHI indicators in the near future.

8. Policy recommendations

8.1 Enhance accountability under international law and uphold the enforceable right to adequate food: Governments must reinforce their legal commitments to eliminate gender-based discrimination, uphold the right to food, and combat hunger—especially in times of crises and conflict—by adhering to the Voluntary Guidelines on the Progressive Realization of the Right to Adequate Food and other relevant international frameworks.

8.2 Advance gender-responsive strategies in food systems and climate initiatives: For policies and programs to be effective and contextually relevant, it is essential for decision-makers and implementers to understand how climate resilience and food systems are shaped by varied needs, vulnerabilities, and socio-economic factors — particularly gender roles, power relations, and labour divisions.

8.3 Prioritize inclusive investments that advance gender, climate, and food equity: Governments should reallocate public spending to address deep-rooted inequalities and ensure fair access across genders. For instance, funding directed toward sectors such as caregiving, education, healthcare, and rural development can play a key role in challenging discriminatory practices and fostering a more balanced sharing of responsibilities within families and communities.

9. Conclusion

India's struggle with food and nutrition insecurity, as reflected in its low Global Hunger Index ranking, highlights persistent challenges such as child undernutrition, gender disparities, and systemic delivery gaps. However, the country's strong social equity framework offers significant potential for progress. Notably, India holds a Gini Index of 25.5, ranking as the

fourth most equal society in the world, ahead of all G7 and G20 nations. This remarkable achievement demonstrates that India's economic growth is being shared more evenly, laying a robust foundation for reducing hunger, improving child nutrition, and enhancing public health outcomes. With sustained efforts in inclusive welfare delivery, maternal-child health, dietary diversification, and gender-responsive policy, India is well-positioned to accelerate its progress toward achieving SDG 2: Zero Hunger. Leveraging this equity advantage through integrated, nutrition-sensitive, and rights-based strategies will be pivotal in transforming India's food systems and improving its GHI performance in the years ahead.

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Government Schemes and Policies Addressing Hunger and Nutrient in India

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Abstract

World largest countries are India with more than 1.3 billion people living there. Even though the economy is still growing quickly, the country still has big problems with hunger, malnutrition, and food insecurity because many people have insufficient foods and nutrients. 2nd Sustainable Development Goal of United Nations is Zero Hunger and rate of malnutrition and hunger must be decreased. This goal is to end world hunger by 2030. But India is still behind in the Global Hunger Index, coming in 105th out of 127 countries. Our neighbors, on the other hand, have done better that is Pakistan is 102nd, Bangladesh is 81st, Nepal is 69th, and Sri Lanka is 60th. Many programs are launched by Government of India in taking care of women and children health and nutrition status. These include making their diets better and more plentiful, preventing micronutrient deficiencies like anemia, making it easier for them to get the nutrition and health services they need, improving water and sanitation facilities, and promoting education, especially about nutrition. It is also very important for the health of mothers and children to give women the power to put off getting pregnant and space out their pregnancies. Despite ongoing initiatives, policies, and programs in India have predominantly concentrated on postnatal feeding interventions, neglecting the significance of maternal nutrition during fetal development. Article involve current status of hunger, malnutrition, and food security in India, as well as the government's plans and policies and possible solutions.

Keyword: Children, Hunger, Health, Malnutrition, Nutrition

1. Introduction

Approximately 6.3 million children die annually under age of five with 165 million are malnourished globally. The public health situation in South Asia is critical, with 165 million

children stunted, 101 million underweight, and 52 million wasting as of 2015. Fifty percent of youngsters in these regions fail to fulfill their daily nutritional requirements and are undernourished. Bangladesh, India, and Pakistan are three nations in South Asia having a significant population of malnourished children. India among world's 2nd most populated country, following China, with population of 1.21 billion individuals. Approximately 26 million children are born annually in this location. The 2001 and 2011 censuses indicated an absolute growth of 181 million and a reduction of 5.05 million in the kid population. Kids' population declined by 3.1 percent in 2011 relative to 2001. Infectious diseases such as malaria, pneumonia, diarrhea, HIV, and tuberculosis pose significant risks to children less than five years of age. Non-communicable diseases, injuries, and armed conflict pose significant threats to older children. Despite being fully preventable and treatable, prevalent infectious diseases continue to claim the lives of numerous young infants. Pneumonia, diarrhea, and malaria constituted almost 30% of all deaths among children under five years old in 2019. 9.10 In addition to infectious and various non-communicable diseases, malnutrition persists as a significant issue, particularly in nations such as India, which has had notable economic progress and a reduction in monetary poverty over the past two decades. Malnutrition in children constitutes a public health concern in numerous developing countries. Low birth weight is a significant indicator of malnutrition. It significantly hampers economic potential in numerous countries while also inflicting substantial physical and mental distress in academic performance. Malnourished children require increased care from their parents and have diminished physical and cognitive productivity compared to adults. Malnutrition constitutes a breach of a child's human rights. Hunger and undernourishment perpetuate a cycle that is transmitted between generations. According to the Global Nutrition Report of 2016 and 2nd Sustainable Development Goal of United Nations is Zero Hunger with objective of nations globally is to eradicate hunger and malnutrition by 2030. The Global Nutrition Report of 2020 intends to accomplish 6th nutrition indices in 2025 and seeks to decreased restriction in children by 40%. According to World study, Food Security and Nutrition have aim of Zero Hunger by 2030 will be unmet by around 660 million individuals. Malnutrition denotes a cellular disparity between the body's energy requirements and the energy and nutrients available for growth, as well as difference in individual's diet (Traczyk *et al.,* 2021). According to WHO defines malnutrition as encompassing three distinct types of conditions: Under nutrition these categories of malnutrition include wasted (low weight-for-height), stunted (low height-for-age), and underweight (low weight-for-age), with underweight being the primary cause of mortality globally. Micronutrient-related malnutrition includes deficits in vital vitamins and

minerals or an overabundance of micronutrients. Overweight, obesity, and non-communicable diseases linked to diet, such as diabetes, heart disease, stroke, and some types of cancer, are all included in class three.

1.1.Understanding the Complexity of Hunger and Malnutrition

Hunger often indicates the unease resulting from insufficient caloric intake. Taking into account variables like sex, age, height, and degree of physical activity, the Food and Agriculture Organisation of the United Nations (FAO) define food deprivation, also known as undernourishment, as the persistent consumption of insufficient calories to meet the minimum dietary energy requirements required for a healthy and productive life. Under nutrition means not getting enough calories, but it also means not getting enough energy, protein, and important vitamins and minerals. Under nutrition can occur due to insufficient food intake in terms of quantity or quality, impaired nutrient absorption resulting from infections or diseases, or a combination of these factors. (Akbarian *et al.,* 2024). There are a number of underlying problems that affect the immediate causes. These include not having enough food at home, not having good maternal health or childcare practices, and not being able to get health care, safe water, and sanitation. Malnutrition encompasses both under nutrition, caused by deficiencies, and over nutrition, stemming from imbalanced diets marked by excessive caloric intake, with or without inadequate consumption of micronutrient-rich foods. Over nutrition leads to issues like being overweight, being obese, and getting non-communicable diseases, which are becoming more common. Under nutrition is more than just not getting enough calories; it has an effect on people's health, government spending, and the way food systems around the world are changing. Over nutrition is a significant concern; however, the Global Hunger Index (GHI) exclusively addresses issues related to undernutrition. Malnutrition: Table 1 shows that 18.3% of children aged 0 to 2 years were undernourished, and 16.2% of children aged 7 to 9 years were undernourished. For kids between the ages of 14 and 16, the rate of undernourishment was 14 percent. For kids between the ages of 20 and 22, it was 16.6 percent. A significant proportion of children less than five years old suffer from both child stunting and child wasting, according to data. In 2000, 9.2% of children died, but by 2021, that number had dropped to 3.1%.

Table 1: India's situation with regard to undernourishment, child waste, stunting, and child mortality among children under five

Indicator	Time Periods	India (%)
Undernourishment (% of population)	2000–2002	18.3
	2007–2009	16.2
	2014–2016	14.0
	2020–2022	16.6
Child wasting (% of children under five years old)	1998–2002	17.8
	2006–2010	20.0
	2013–2017	18.0
	2018–2022	18.7
Child stunting (% of children under five years old)	1998–2002	51.0
	2006–2010	47.8
	2013–2017	38.3
	2018–2022	35.5
Child mortality (% of children under five years old)	2000	9.2
	2008	6.5
	2015	4.4
	2021	3.1

According to the represented data in Table 2 percentage of Undernourishment, Wasting, and Stunting of different age group people varies from Children under 5 are stunted by 35.5 %, women of age group (15-49) are anemic by 50 % and poor people who spend more than 50% of income on households are being 60% among Indian population.

Table 2: Status of Undernourishment, Wasting, and Stunting of various age groups in India

S. No	Key Indicators	Percentage
1.	Children under 5 are stunted (low height for age)	35.5 %
2.	Children under 5 are wasted (low weight for height)	19.3%
3.	Children under 5 are underweight	32%
4.	Adult women in the age group (15-49) are anemic	50 %
5.	Poorest households spend over 60% of their income on food	60%

Stunted Child | Wasted child | Underweight child | Anemic women

Fig. 1. Depicting malnutrition of various age group children

2. Early Food Security Policies in Independent India

As previously said, India adopted a mixed economy model wherein the public and private sectors collaborated. The Planning Commission had a crucial role in creating the Plan texts and monitoring economic public policy. The public sector's role gradually shrank following the 1991 economic reforms. With the formation of a new government in 2014, the Planning Commission was eventually abolished. However, up until that point, the government's plans for handling various policies during the plan periods were outlined in the Five-Year Plan documents. A plan exercise's primary objective was to achieve the maximum GDP growth achievable with the resources at hand, as well as the appropriate spectral composition and investment distribution across sectors. Potential investments in areas like health, nutrition, and education that might enhance societal welfare improved this primary exercise. The 5th Plan, which made certain assumptions about how consumption is distributed, was the first to attempt to establish a formal target for poverty reduction and connect it with a goal for GDP growth.

The primary policies that were employed to ensure that everyone had enough food are discussed after a brief discussion of the nutrition policies that were based on some of the Five-Year Plans (Dev, Ganesh-Kumar, & Pandey, 2024).

Nutrition Security

The government started 1St Five-Year Plan in 1951. It said that nutrition was important for keeping people healthy and that it affected how much work a person could do. It noted that there was a lot of under-nutrition in the country and that there wasn't enough protective food to go along with the main cereals, which led to malnutrition. The Second Five-Year Plan openly said that it was not possible at the time to give everyone the best nutrition possible during the Plan period. It recognized that harm to healthy growth and development at a young age "cannot be made good even by providing adequate nutrition at a later age," thus it began certain programs to promote nutrition for vulnerable categories of people, including children, newborns, and pregnant and nursing mothers. 3rd Five-Year Plan also said something similar. The Fifth Five-Year Plan's Minimum Needs Programmed (MNP) aimed to provide certain basic social services and facilities up to certain standards. The MNP engaged in two types of activities: (a) basic infrastructure for area development activities, such as rural roads and village electrification, and (b) fundamental human resources development activities, such as health, drinking water supply, nutrition, and rural housing. Following that, the MNP included new initiatives including urban slum development, sanitation, and cooking energy to a number of plans. The contributions of each component—beneficiary development and area development—to increasing productive capacity were investigated. The addition of public distribution to the MNP list during the 7th Plan is intriguing. In order to support preschoolers' social and academic development as well as their health and nutrition, the Integrated Child Development Services (ICDS) Program was established in 1975. Additionally, it sought to care for moms and ensure that they received the nutrients they required. Anganwadi personnel provide additional nourishment, immunisations, health examinations, referrals, and preschool instruction under ICDS. It started in specific blocks and gradually extended to other locations. Similarly, initiatives were launched to prevent blindness, anaemia, and iodine deficiency illnesses brought on by a shortage of vitamin A. The Sixth Plan included extensive information on nutrition. It believed that increasing nutrition mostly depended on the family's awareness, income, and knowledge and that improving nutrition required earning money and having a job. It stated, "The best and cheapest way to improve the nutritional status of families is to get them jobs." Therefore, a major component of the nutrition policy of the 6th Plan was the availability

of a minimum income or assistance in escaping poverty. But it also acknowledged the significance of other factors, such as food production, post-harvest processing, storage, the expansion of the network of fair pricing stores, the midday meal program, cropping pattern adjustments, fortified food, and the participation of community-based organizations. According to the National Nutrition Monitoring Bureau, which was referenced in the 7th Plan, nearly half of the households polled consumed food that was insufficient in calories, protein, or both. Merely 15% of children were deemed to be in good nutritional status; the remaining youngsters were somewhat undernourished. By defining the objectives of nutritional policy as improving the workforce's functional efficiency and lowering the rates of infant and maternal mortality, the 7th Plan added a new dimension.

This suggested that the Planning Commission was more swayed by the practical application of nutrition than by its inherent worth. In terms of policy tools, the 7th Plan's response to the nutrition issue was comparable to that of the first two plans. It viewed "expanding job opportunities and stabilizing income, especially among vulnerable groups," as the primary long-term strategy for ensuring adequate food for people. Enhancing the public distribution system (PDS) to provide families with a healthy diet at "reasonable prices" by incorporating both cereals and non-cereal goods was another goal. It also emphasized the significance of educating people about safe drinking water, proper sanitation and hygiene, proper nutrition, and allowing children adequate time between births. According to the 10th Plan, "nearly 60% of pregnant women are anaemic, 30% of newborns are significantly underweight, and over half of children under five in India are moderately or severely malnourished. It investigated how malnourishment impacts "cognitive development and learning achievements, lowers the ability to work and productivity among adults, and raises mortality and morbidity among children." According to the report, "nutritional deficiency diseases," including blindness from severe vitamin-A deficiency, Kwashiorkor, marasmus, pellagra, lathyrism, and beriberi, are now uncommon. According to the 10th Plan, people's eating patterns were shifting away from consuming grains and food together due to factors like age, occupation, and income. Since many non-grain goods had limited shelf lives and the minimum support prices needed to be adjusted to encourage a wider variety of foods, it believed that the shifting patterns of consumption were beneficial for nutrition and supported the construction of storage facilities. In order to assist those who were not obtaining enough food, it also promoted the utilisation of enormous public food grain supplies that had been accumulated by that point. Better child nutrition, better childcare, access to clean drinking water, improved sanitation, and

immunizations were among the many reforms that the 11th Plan called for. It claimed that the National Rural Health Mission might lower the cost of curative medical care. During the 11th Plan period, it acknowledged the need to raise public health spending to at least 2% of GDP. We have discussed the evolution of government policies on malnutrition. The prevalence of malnutrition and under nutrition has long been recognized by policymakers. Although they were first recognized in the 1950s and 1960s, several of the major issues with nutrition in India were discussed in the 2010s and 2020s. Resources were obviously a major issue at the time (Dev, Ganesh-Kumar, & Pandey, 2024). In the first few decades after independence, the problem of starvation was nearly acknowledged as unsolvable. Rather, the emphasis was on maternity and child care, which required urgent attention. Programs like as ICDS were initially tested in small populations, but when more resources became available, they were extended to additional regions. Studies that examined ICDS have discovered issues with it, such as inadequate cold chains for vaccines, delayed delivery of nutritional supplements, and even improper meals. Over time, officials became aware of the problem's various facets, including the necessity for sanitary facilities and safe drinking water. Calorie intake, which is more closely linked to grain consumption, has always been closely monitored by the government.

Food Security

Because of low productivity and population growth, policies had to be changed a lot to make more food grains to meet domestic demand. A country as big as India couldn't rely too much on imports because the global grain market isn't very big, especially for rice, which only makes up about 10% of global consumption. There isn't a lot of international trade in wheat, but food grains markets are full of cartels. Policymakers knew that making food grains, which are a staple food for Indians, had to be a big part of the food security plan. But the strategy didn't halt trade with other countries since in years when there wasn't enough of something, some imports were needed to make up for it, and in other years, some exports were needed to get rid of the excess. The Green Revolution started in 1968 for rice and wheat. It includes high-yielding variety (HYV) seeds, irrigation, chemical fertilizers, pesticides, and the usage of tractors. Farmers in Punjab, Haryana, Western Uttar Pradesh, and sections of Tamil Nadu and Andhra Pradesh were the first to use the new technology that revolutionized how food was cultivated. Research and extension services helped them. The HYV worked very effectively to increase wheat crop yields. Reforms in institutions, such as the merging of assets that had been done in a number of states, made it possible to deploy modern technologies. Pricing gave farmers more reasons to work hard, and banks gave agriculture first dibs on credit. The

revolution slowly spread to other parts of the country. The green revolution was clearly a success because India became self-sufficient in grain in the 1970s. This was a very important first step for India in its search for food and nutrition security. The Green Revolution was a big part of many programs, and the money needed for it was set aside. India has been a net exporter of cereals since the 1990s, it turns out.

3. Key Government Schemes Addressing Hunger and Malnutrition

[1] National Nutrition Policy (1993) and National Plan of Action on Nutrition (1995): According to the National Nutrition Policy (1993) and the National Plan of Action on Nutrition (1995) have prioritized the provision of adequate nutrition for women and children. In recent years, a more focused effort has been undertaken in this domain. In pursuit of rendering India "Kuposhan Mukt" (free from malnutrition), NITI Aayog, a branch of the Indian government, created the "Nourishing India" document in 2017. This method underscores the importance of preventing and mitigating undernutrition at all life stages, particularly during the first three years, to avert cumulative, irreversible growth and developmental deficits that could threaten survival and health. The attainment of Sustainable Development Goals at both national and international levels is impeded by elevated rates of malnutrition. The Budget 2014–15 addresses emphasized the urgent necessity for national-level mission-mode projects to mitigate the deteriorating nutritional status in our country. This underscored the significance of nutrition and facilitated the establishment and implementation of the POSHAN Abhiyan in 2018. The Prime Minister's Overarching Scheme for Holistic Nutrition (POSHAN Abhiyan) is the Ministry of Women and Child Development's main program. Its goal is to improve the nutrition of children, pregnant women, and nursing mothers. The Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), the National Health Mission (NHM), the Swachh Bharat Mission, the Public Distribution System (PDS), the Pradhan Mantri Matru Vandana Yojana (PMMVY), the Scheme for Adolescent Girls (SAG), the Janani Suraksha Yojana (JSY), and the Integrated Child Development Services (ICDS) are all part of this initiative, and the Ministry of Drinking Water & Sanitation. In order to reduce stunting, undernutrition, and anaemia in young children, women, and adolescent girls, as well as low birth weight deliveries within a given timeframe, the Abhiyan's primary interventions include infant and young child feeding (IYCF), nutrition, institutional childbirth, water sanitation and hygiene (WASH), deworming, ORS-Zinc provision, food fortification, dietary diversification, adolescent nutrition, maternal health and nutrition, and early childhood development (ECD)/early childhood care and education (ECCE).

[2] Revised Scheme for Adolescent Girls (SAG): The new Scheme for Teenage Girls (SAG) under POSHAN 2.0 aims to help girls ages 14 to 18 with their nutrition, IFA supplements, health checkups and referrals, skill development, and nutrition and health education.

[3] Conditional cash transfer schemes: Pregnant and breastfeeding women who fulfil specific requirements can receive financial assistance through the Janani Suraksha Yojana (JSY) and Pradhan Mantri Matru Vandana Yojana (PMMVY). On the ninth day of every month, the Ministry of Health & Family Welfare's Pradhan Mantri Surakshit Matritva Abhiyan (PMSMA) aims to ensure that all expectant mothers receive comprehensive, free, and high-quality prenatal care. Additionally, it aims to ensure that pregnant women in the second or third trimester receive a minimal set of prenatal care services.

[4] Janani Shishu Suraksha Karyakram (JSSK): The goal of this program, which started in 2011, is to make sure those pregnant women and sick newborns don't have to pay for anything out of their own pockets and that all births happen in a hospital. Expectant mothers can also get free services like cashless delivery or cesarean sections, medications and consumables, diagnostics, daily meals (while they are in the hospital), transportation, and more.

[5] National Iron Plus Initiative (NIPI) or Anemia Mukt Bharat: Some programs that have made a big difference in reducing or preventing malnutrition are the National Iron Plus Initiative (NIPI), also known as Anemia Mukt Bharat (the Intensified NIPI), the National Program for Nutritional Support to Primary Education/Mid-day Meal Scheme (currently known as Prime Minister-Poshan Shakti Nirman, or PM-POSHAN), and the Prevention of Blindness due to Vitamin A Deficiency. The National Policy for Women in 2016 aims to meet the needs of women in many ways. The MoWCD's (2021) Poshan Tracker is a governance tool that aims to make nutrition delivery systems better and more open. Technology is being used to find out if kids are stunted, wasted, or underweight, as well as to keep an eye on how well nutrition services are being used.

[6] Pradhan Mantri Poshan Shakti Nirman (PM POSHAN): National Education Policy (NEP) 2020 says that India's PM POSHAN program, which used to be called the mid-day meal program, is a very important way to combine education with food and nutrition activities. The National Food Security Act, 2013 (NFSA) has a main rights-based Centrally Sponsored Scheme called PM POSHAN that helps about 12 crore children in 10.84 lakh government and government-aided schools across the country. The program's goals are to solve the problems of hunger and education at the same time by: [a] Improving the nutrition of children in

government, government-aided, and Special Training Centre (STC) classes I through VIII and Bal Vatika. [b] Getting kids from low-income families to go to school every day and take part in class. iii. Helping primary school-aged kids in areas affected by drought with their food needs during the summer and in emergencies.

[7] School Health and Wellness Programme: School Health Program is part of AYUSHMAN BHARAT and is run by the Ministry of Education and the Ministry of Health and Family Welfare. The goal of this program is to get the most out of learning at school and to encourage a holistic approach to health promotion. Each public school gets two Health and Wellness Ambassadors (HWAs), one male and one female. These teachers are trained to teach kids about disease prevention and promote healthy habits through fun activities in the classroom every week. The program includes meals at noon, weekly iron and folic acid supplements, nutrition counseling, help avoiding tobacco, and lessons in life skills to help treat childhood anaemia.

[8] Mission Saksham Anganwadi and Poshan 2.0: Ministry of Women and Child Development (MoWCD) runs this integrated nutrition assistance program. It tries to make it more effective and efficient by adding a number of features: i. Tithi Bhojan: A program that gets kids involved in the community by giving them special food on holidays and other important days. ii. School Nutrition Gardens: Making nutrition gardens at schools so that kids can learn about gardening and being outside. There are already more than 4 lakh schools in India that have these kinds of gardens. iii. Every district must do a social audit of the scheme. iv. Special rules for giving kids in areas with a lot of anemia and areas that want to be better access to extra nutrition products. v. Promoting culinary contests at all levels to encourage ethnic cuisine and creative meals made with ingredients that are easy to find in the area. Vii. Atmanirbhar Bharat Vocal: Farmers Producer Organizations (FPO) and Women Self-Help Groups' involvement in carrying out the plan, with an emphasis on using traditional foods made in the area to help the economy grow. To get the best nutritional results, Poshan 2.0 has reorganized programs like Poshan Abhiyan, Anganwadi Services, and the Scheme for Adolescent Girls. It focuses on three main things: improving Anganwadi buildings, providing care and education for young children (ages 3 to 6), and helping mothers, children, and teenage girls with their nutrition. Poshan 2.0 wants to fix the problems of malnutrition, teach people more about nutrition, encourage people to eat healthy foods for their long-term health and well-being, and strategically fix problems related to nutrition (Sharma & Singh, 2018). The Ministry of Women and Child Development says that as of June 2022, the program was running through 13.91 lakh Anganwadi Centres (AWCs) and 7074 fully functional Projects. 951.35 lakh people

get services, including 180.37 lakh pregnant and nursing women and 770.98 lakh kids under six. Also, as of June 2022, 303.17 lakh kids ages three to six were in pre-school programs. Poshan Tracker is an ICT-enabled platform that lets you keep an eye on things in real time. It is easier to keep an eye on what is going on at Anganwadi Centres, what Anganwadi Workers do, and the full administration of beneficiaries.

[9] POSHAN Abhiyaan: In order to lower the national rate of malnutrition and improve the nutritional health of young children (ages 0–6), teenage girls, pregnant women, and nursing mothers within a specific timeframe, the Hon. Prime Minister launched the POSHAN Abhiyaan in 2018.

[10] Poshan Bhi, Padhai Bhi: As part of Mission Saksham Anganwadi and Poshan 2.0, the Ministry of Women and Child Development launched the flagship project "Poshan Bhi, Padhai Bhi" on May 10, 2023. This plan prioritizes Early Childhood Care and Education (ECCE) and covers 1.3 million Anganwadi Centres nationwide. In order to ensure the holistic development of children under six, it seeks to convert Anganwadi centres into centers for education and nutrition, with a focus on developing competences in critical developmental domains specified by the National Education Policy (NEP) (Sarma, 2024).

4. Recent Initiatives and Reforms

4.1 One Nation One Ration Card (ONORC)

The One Nation One Ration Card (ONORC) program was started in 2018 by the Department of Food and Supplies and Consumer Affairs, which is a division of the Ministry of Consumer Affairs, Food, and Public Distribution. The goal of this government initiative is to ensure food security for all individuals who fall under the category of internal migrants. Under the National Food Security Act (NFSA), this program allows participants to have ration cards connected to their Aadhaar, which makes it easier for them to access the Public Distribution System (PDS) and use Fair Price Shops (FPS) across the country. It states that food grain in the state of residence is continuously authorized, either fully or partially.

4.2 Fortification of Rice, Wheat, and Edible Oil

The fortification of rice is a pilot initiative launched in 2019, designed to enhance the nutrition program by boosting the availability of fortified rice enriched with iron, folic acid, and vitamin B12, in accordance with government-established criteria. It aids in combating anaemia, malnutrition, and concealed hunger among the populace. This initiative aims to enhance the

levels of vital micronutrients, vitamins, and minerals in food to improve nutritional quality and promote public health with low health risks. The National Family Health Service survey indicates that around 78.7% of children and 75% of the district's population are afflicted by anaemia and malnutrition.

5. Challenges in Ensuring Nutrition Security

The Global Hunger Index is an instrument for systematically assessing and monitoring hunger on global, regional, and country scales. The scores are derived from four component indicators: undernourishment assessed by caloric intake, stunting in children under five measured by height, wasting in children under five evaluated by weight, and child death before age five. With 0 representing the ideal score (lack of hunger) and 100 representing the most severe hunger, the GHI score, which is based on the values of four indicators, represents the intensity of hunger. Pakistan (102), Bangladesh (81), Nepal (69), and Sri Lanka (60), which are all close to India, have done better in the rankings. In 2024, India is ranked 105th out of 127 nations.

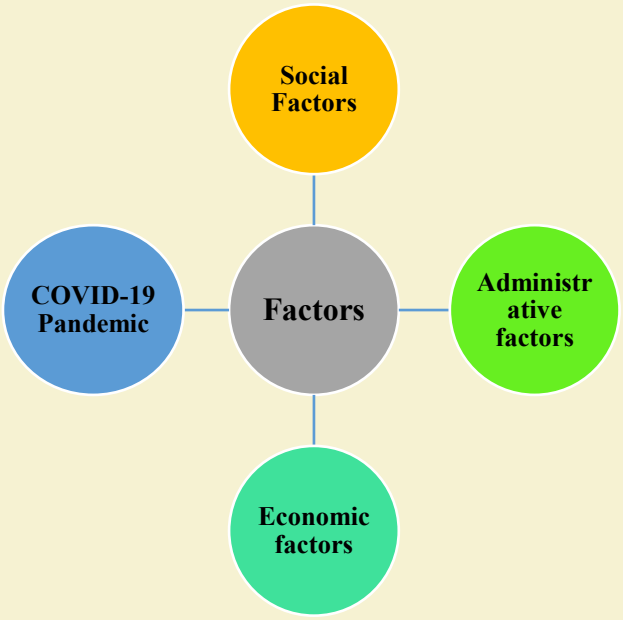

Fig. 2. Factors affecting India's trailing in GHI

(a). Social factors-

1) **Prevalence of Poverty:** 23.6% of the Indian population, around 276 million individuals, subsisted on less than $1.25 per day based on buying power parity.
2) **Gender inequality**: signifies that women receive the least nourishment and are served last. Nutritional deficiencies exert an intergenerational impact on women, particularly

among marginalized areas. Research indicates that 56 percent of Dalit women and 59 percent of tribal women are anemic, compared to a national average of 53 percent.

(b). Administrative factors- Exclusion from NFSA: The national government utilizes the 2011 population data from the most recent census to determine state-specific PDS coverage. Upon the implementation of the NFSA in 2013, the population figures from the 2011 census were current. Nonetheless, the statistics ought to have been periodically revised with anticipated population data.

1) **Problem of interoperability** of ration cards in the case of migrant population.
2) **One Nation One Ration card** has not been scaled up.
3) **Open-ended procurement** of rice and wheat at the opportunity cost of **nutri-cereals** like Jowar, Ragi, Bajra etc.
4) **Rampant corruption:** The black market is thought to regularly receive between 30 and 70 percent of the subsidized food grains that are given through half a million fair-price ration stores.

(c). COVID-19 Pandemic: The Integrated Child Development Scheme services were either completely unavailable or seriously interrupted during the pandemic.

- Mid-day meal scheme was affected due to the closure of schools.
- Due to the pandemic, many Anganwadis have closed, and many that have reopened lack adequate, hygienic facilities, water connections, and prepared meals.
- Ongoing 2021 State of Food Security and Nutrition in the World (SOFI) report noted that the COVID-19 epidemic has had a detrimental impact on SDG 2, which aims to achieve "Zero Hunger."

6. Future Perspectives and Policy Recommendations

Policy initiatives are critical in tackling nutrition and hunger issues in India. Several policies that contribute to enhancing future prospects in India include:

- Enhancing food grain output to provide food security.
- By promoting the production and accessibility of nutritionally dense food items, we aim to enhance the population's dietary habits.
- Enhancing the purchasing power of the impoverished and reducing their vulnerability to enable the acquisition of a balanced, nutrient-rich diet.
- Enhancement and augmentation of the public distribution system

- Enhancing student understanding of nutrition via educational curriculum, among other methods (Panda, 2024).
- Food adulteration must be checked and prevented.
- Enhance community engagement in nutritional monitoring.

CONCLUSION

Ministry of Women and Child Development's integrated nutrition support programs exemplify a concerted effort to tackle the intricate challenges of malnutrition and ensure the comprehensive development of India's most at-risk populations. The POSHAN Abhiyaan and Poshan Bhi, Padhai Bhi initiatives, together with the Mission Saksham Anganwadi and Poshan 2.0 programs, underscore the government's commitment to enhancing nutritional outcomes and fostering early childhood care and education. These initiatives, with innovative components such as Tithi Bhojan and School Nourishment Gardens, aim to empower communities to actively participate in fostering healthy lifestyles while also delivering essential nutrition. A comprehensive strategy for mitigating nutritional deficiencies and promoting long-term health and well-being is underscored by an emphasis on social audits, supplemental nutrition initiatives, and local economic empowerment measures. Moreover, employing ICT-enabled solutions for real-time monitoring demonstrates a commitment to accountability and transparency in plan implementation, ensuring effective service delivery and beneficiary management. These projects are fundamental components in India's endeavor to establish healthier, more resilient communities while striving to achieve the vision of "Suposhit Bharat" and address the pervasive issue of malnutrition. These programs, prioritizing nutrition and education, establish a robust foundation for the future prosperity and well-being of the nation's women and children, paving the way for a healthier and more promising India.

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Rational approaches to enhance the Seed Replacement Rate (SRR) to ensure Food and Nutritional Security

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Abstract

Seed Replacement Rate (SRR) — the proportion of area sown with certified/quality seed rather than farm-saved seed — is a high-leverage indicator affecting productivity, resilience, and nutrition outcomes. This chapter (a) defines SRR and explains its policy relevance for food and nutritional security; (b) presents rational technical, institutional, and market approaches to raise SRR at scale; and (c) documents an applied institutional example — RPCAU (Pusa) and its RAJENDRA PUSA BEEJ® programme — including participatory seed production, infrastructure, training, and measured impacts. Evidence and programme data come from RPCAU operational reporting and program slides. The chapter closes with an assessment of remaining challenges and practical recommendations for extension managers and policy makers.

Keywords: Food security; Farmer-Producer Organizations: RAJENDRA PUSA BEEJ®; Seed Replacement Rate (SRR); Seed systems; Participatory seed production; Seed traceability.

Introduction

Seed is one of the most important inputs for sustainable agriculture. The genetic potential in seeds is a major determinant of the effectiveness of all other agricultural inputs, including

fertilizers, water, and agrochemicals. The Seed Replacement Rate (SRR), one of several seed-related indicators, is crucial in determining farm output and, consequently, the food and nutritional security of the country. Indian Seeds Programme recognizes three generations of seeds: breeder, foundation, and certified seeds. Certified seeds are seen to be directly proportional to crop productivity. However, the Seed Replacement Ratio (SRR) – a measure to assess the use of certified or good quality seeds requires significant scaling up in India. The replacement rate in most field crops is much below the optimum level, largely due to the huge demand-supply gap. Around 15% of India's total cropped area is planted with freshly obtained quality seeds every year. A huge 85% area is sown with farm-saved seeds. This ratio varies from crop to crop. The Sustainable Development Goals (SDGs) enshrined in the United Nations Development Program (UNDP) aim to end hunger and achieve food security through improved nutrition and sustainable agriculture. However, climate change is already impacting agricultural productivity and food systems, making global food supply chains increasingly vulnerable to shocks and disruptions (The Sustainable Development Goals Report, 2018). The Seed Replacement Rate (SRR) is the rate at which farmers replace on-farm stored seeds with certified, high-quality seeds. Improving SRR can significantly increase crop yields, improve resilience to climate stressors, and support the adoption of climate-resilient varieties. By integrating improved seeds into agricultural systems, particularly those bred for drought tolerance, disease resistance, and shorter growing cycles, these countries can increase their agricultural production and move closer to food security in the face of a changing climate. The seed replacement rate (SRR) is a crucial metric for assessing the extent to which farmers are transitioning to improved varieties and hybrids, rather than relying on farm-saved seeds. A data review from 2019 to 2021 indicates that cereals, including rice, maize, jowar, and bajra, have achieved the highest SRR across numerous states. Andhra Pradesh and Telangana are particularly notable, with nearly complete adoption of rice and maize, while Gujarat, Rajasthan, and Maharashtra exhibit similar success with hybrid millets like jowar and bajra. In contrast, wheat, a vital food crop in northern and central India, has demonstrated moderate advancement. States such as Uttar Pradesh, Madhya Pradesh, and Rajasthan are performing better in this regard, whereas southern states show comparatively lower replacement rates. The scenario is markedly different for pulses. Crops such as gram, moong, urd, and lentil have not reached the seed replacement levels of cereals, with most states reporting rates below 50 percent. This suggests that a significant number of farmers still depend on traditional farm-saved seeds. The trend in oilseeds is mixed: soybean replacement is moderate in Madhya Pradesh and Maharashtra, while groundnut adoption is more pronounced in Gujarat and Andhra Pradesh.

The situation with cash crops presents a varied picture. Cotton, in nearly all states, demonstrates almost complete adoption of hybrid seeds, and sunflower also achieves a high SRR. In summary, while cereals and cash crops have made important advances, pulses and certain oilseeds still necessitate targeted initiatives to enhance the adoption of quality seeds.

Table 1: Crop-wise seed requirement and availability of quality and certified seeds

Crop Name	2019-20		2020-21		2021-22	
	Req.	Availability	Req.	Availability	Req.	Availability
Wheat	121.69	139.55	124.75	151.44	133.79	144.4
Paddy	82.4	92.28	98.79	108.75	103.33	120.21
Ragi	0.28	0.49	0.33	0.53	0.5	0.61
Barley	1.98	3.04	1.96	3.7	2.08	2.72
Maize	12.71	15.07	14.99	16.13	14.47	13.52
Bajra	2.51	2.74	2.44	2.69	2.39	2.61
Jowar	2.28	2.73	2.42	2.72	1.95	2.21
Gram	21.06	23.76	22.03	23.71	21.71	23.68
Urad	3.11	3.51	3.26	3.67	3.47	3.58
Moong	2.45	3.31	2.48	3.37	2.45	3.11
Groundnut	21.33	25.52	26.35	26.7	26.4	28.28
Soybean	30.41	33.42	27.23	24.03	29	28.12
Cotton	2.15	2.44	2.47	2.78	2.4	2.73

Source: Department of Agriculture & Farmers Welfare- annual report 2022

Seed Replacement Rate (SRR): Concept and Policy Relevance

The Seed Replacement Rate (SRR) measures the proportion of a crop's sown area planted with certified or high-quality seed rather than farm-saved seed. In practice, it is expressed as the percentage of total cropped area replanted each season with new, certified seed (e.g., hybrids) instead of recycled seed from previous harvests. A high SRR signals rapid adoption of improved genetics and is strongly linked to higher yields and output (Chakraborty, 2025).

Globally, modern seed industries strive for high SRRs — in many developed countries SRRs for major crops (especially hybrids and F1 varieties) approach 100%, since farmers buy new seed each year. By contrast, in most low-income countries SRRs are much lower. For example, more than 80% of crops in developing countries are still sown from farmer-saved seed (FAO, 2023). In India, only about 15% of arable area now uses certified seed annually, even though policy studies recommend 20–30% or higher for key staples (Srivastava, 2018). These gaps mean large yield and income foregone. For context, India's seed industry is now the world's 5th largest (≈4.4% of the global market), but usage of certified seed is far below international norms (Chakraborty, 2025).

Definition and Measurement: SRR is defined as the percentage of a crop's area planted with certified seed each year. Formally,

$$\mathbf{SRR}=\left(\frac{\textbf{Area Certified Seed Used}}{\textbf{Total Crop Area} \times \textbf{Seed Rate}}\right) \times \mathbf{100}$$

(Singh *et al.,* 2023). Hybrid crops (which must be replanted every season) effectively have a 100% SRR by design. In India, average SRRs vary widely by crop and region: only ~9–18% for staple cereals like rice and wheat nationally, versus ~70% or more for certain vegetables (Srivastava, 2018). Within India's states, SRRs also differ starkly—e.g., Andhra Pradesh's paddy SRR is about double the national average, whereas Uttarakhand's is only ~25% of the average (Chakraborty, 2025).

- **Global Perspective:** In North America and Europe, certified seed use is nearly universal for major crops, so SRRs often exceed 90%. By contrast, in many African and South Asian economies, farmers reuse seeds for several seasons, driving SRRs below 20% (FAO, 2023). International seed research networks (e.g., CGIAR) emphasize raising SRR through varietal adoption.
- **India's Situation:** India's National Seed Policy (2002) has aimed to raise SRR by improving seed production and distribution. Nevertheless, the overall SRR in India hovers around 15–20% (Srivastava, 2018). Some of the highest SRRs occur in hybrid cotton (≈100%) and select high-yielding cereal zones, but many states lag far behind. Experts note that until 85% of India's cropped area uses quality seed, productivity targets will remain unmet (Singh *et al.,* 2023).

Agricultural Economics Context

From an economic perspective, SRR is directly linked with yield gains and food production. Certified seed alone contributes about 15–20% yield improvement, and when combined with fertilizers and irrigation, the gain can reach 40–45% (Srivastava, 2018). High SRR also accelerates varietal turnover, ensuring farmers quickly benefit from new breeding advances. Low SRR, by contrast, slows productivity growth and results in lost economic value from agricultural R&D. Policies such as India's National Seed Policy (2002) and seed subsidy programs aim to raise SRR, recognizing its multiplier effect on agricultural GDP (Singh *et al.,* 2023).

Rural Development Context

In the rural development dimension, SRR reflects access to quality seed by small and marginal farmers. Low SRRs are often due to weak seed distribution, high input costs, and lack of awareness (FAO, 2023). When SRR rises, yields increase, farm incomes improve, and food security is strengthened. For example, states with higher SRRs (e.g., Punjab in wheat and rice) show better rural prosperity compared to lagging states. Programs like the *Seed Village Scheme* and cooperative seed distribution address these gaps by ensuring the availability and affordability of certified seed to rural communities (Chakraborty, 2025).

Seed Technology Context

From the seed technology angle, SRR indicates how effectively improved varieties reach farms. Hybrid crops (cotton, maize, sunflower) maintain nearly 100% SRR, while self-pollinated crops (rice, wheat, pulses) need regular replacement to maintain vigor. Advances in seed breeding, biotechnology (e.g., Bt cotton), certification, and processing have boosted SRR in certain crops (Sravani *et al.,* 2025). However, inadequate seed multiplication and uneven quality control often constrain progress. Thus, investments in seed testing labs, processing units, and breeding programs remain central to improving SRR and ensuring a reliable supply of superior seed to farmers (Singh *et al.,* 2023).

Rational Approaches to Enhance SRR

Multiple coordinated strategies are needed across the seed value chain to raise SRR. Key approaches include:

- **Breeding and Varieties:** Develop and promote high-yielding, stress-tolerant and nutrient-enhanced varieties (including hybrids). Modern genetics (e.g. hybrid corn, biofortified grains) gives farmers a strong incentive to buy new seed. Accelerating variety turnover through pre-breeding and genomic breeding ensures fresh genetics reach fields faster.

Fig. 1. Seed processing machinery at RPCAU's Dholi Seed Processing Plant, used to clean and bag *Rajendra Pusa Beej* quality seed (Source: RPCAU, Dholi)

- **Quality Seed Production:** Scale up breeder and foundation seed multiplication. Public agencies (ICAR institutes, SAUs, Krishi Vigyan Kendras) and private firms must expand seed production on farms or seed farms. Leveraging **public-private partnerships** (as in India's Seed Village and mini-kit programs) can multiply certified seed supply.

- **Seed Village/Participatory Production:** Empower local communities to produce seed. In the **Seed Village Scheme**, selected farmers are trained and given foundation seed to raise certified seed for distribution in their area. Farmer-Producer Organizations and cooperatives can also aggregate production and marketing of quality seed, ensuring

availability at low cost. (RPCAU, for instance, organized Farmers' Participatory Seed Production programs to engage communities.)

- **Infrastructure and Traceability:** Invest in processing, storage, and quality assurance. Seed processing plants, cleaning and packaging lines (as shown below), and warehousing preserve seed viability and quality. Digital traceability platforms (e.g., "SATHI" portal) can track seed from breeder to farmer. Fig. 1 shows RPCAU's modern seed processing equipment – automatic bagging and grading machines that ensure uniform packaging of certified *Rajendra Pusa Beej*.

- **Policy and Incentives:** Offer subsidies and support schemes. Government initiatives like the SMSP provide credit and subsidies to both public and private seed enterprises. Seed coupon or mini-kit programs partially reimburse farmers for certified seed purchases. Regulatory support (fast-tracking variety release, ensuring adequate breeder seed pricing) also reduces costs and boosts trust.

- **Extension and Education:** Raise farmer awareness of seed benefits. Training sessions, demonstrations, and Kisan Melas highlight that switching to certified seed can increase yields by an estimated 15–25%. Extension workers and agro-dealers play a critical role in advising farmers on seed selection and best practices.

Together, these rational approaches – combining technological innovation, institutional change, and market measures – can progressively lift SRR nationwide.

Crop-wise and State-wise leading seed-producing regions

Table 3. Cereals and Oilseeds Crops leading seed-producing regions

Sl. No.	Crop	Seed production States
1.	Hybrid Paddy	Telangana, Karnataka, Andhra Pradesh, Chhattisgarh
2.	Hybrid Maize	Telangana, Andhra Pradesh
3.	Hybrid Bajra	Andhra Pradesh Karnataka
4.	Hybrid Mustard	Gujarat, Maharashtra, and Andhra Pradesh
5.	Hybrid Cotton	Gujarat, Maharashtra, Telangana
6.	Wheat	Uttar Pradesh, Uttarakhand, Madhya Pradesh, Gujarat, Rajasthan, Haryana,
7.	OPV Rice	Telangana, Andhra Pradesh, Odisha, West Bengal, Uttar Pradesh, Uttarakhand, Madhya Pradesh, Punjab, Haryana

8.	Soybean	Madhya Pradesh, Maharashtra, Telangana
9.	Groundnut	Gujarat, Andhra Pradesh, Karnataka

Table 4. Vegetables and Fruits leading seed-producing regions

1.	Hybrid Tomato	Karnataka, Maharashtra, Gujarat
2.	Hybrid Okra	Gujarat, Karnataka, Maharashtra
3.	Hybrid Chilli	Karnataka, Maharashtra
4.	Hybrid Watermelon	Karnataka, Maharashtra, Gujarat

RPCAU (Pusa) Seed Initiatives: RAJENDRA PUSA BEEJ®

The Dr. Rajendra Prasad Central Agricultural University (RPCAU) at Pusa, Bihar, exemplifies an integrated seed program. Its **Directorate of Seed (DoS) at Dholi** is the nodal unit for producing and distributing quality seed of many crops. The Directorate "produces various categories of seed (nucleus, breeder, foundation, certified)" and collaborates with university farms, KVKs, and private partners to multiply seed stocks. It also includes newly released varieties into its seed chain and conducts training for extension agents and progressive farmers. Crucially, all certified seed sold by DoS Dholi carries the **"Rajendra Pusa Beej"** brand and logo, ensuring a recognized mark of quality for farmers.

Fig. 2. Certified seeds stored by RPCAU, packed in labelled bags. After cleaning, the seeds (various crops) are bagged under quality supervision for sale as Rajendra Pusa Beej. (Source: RPCAU, Dholi)

The Directorate's mandates cover the full seed cycle: production, **processing**, storage, and marketing. It maintains modern infrastructure – for example, four automated seed processing plants with high-capacity cleaners, weighing and bagging machines – to handle thousands of quintals of seed each season (*Figure 2*). This machinery allows RPCAU to process and package certified seed under hygienic, standardized conditions. Processed seed is then stored in controlled warehouses before sale. In fiscal 2023–24, RPCAU reported selling many varieties (rice, wheat, pulses, oilseeds) under the Rajendra Pusa Beej label, directly to farmers and through government distribution channels.

Moreover, RPCAU has invested in **value addition and traceability**. Quality control labs test seed purity and germination. Packets carry detailed labels, and eventually are being integrated into national traceability systems. The DoS's activities (from breeder seed to consumer seed sale) are coordinated to meet institutional and farmers' demand – including government schemes (Mukhyamantri Tibra Beej Bistar Yojana) and emergency contingency plans. In short, RPCAU's Rajendra Pusa Beej program exemplifies how a university-led seed chain can raise SRR through branding, integrated infrastructure and farmer outreach.

Participatory Seed Production and Institutional Innovations

RPCAU actively engages farmers in seed production, recognizing that local involvement boosts SRR. For example, the university ran **Farmers' Participatory Seed Production Programs (FPSPP)** in Bihar villages. These programs train groups of farmers to grow and certify seed (often of their own favoured crops) under technical guidance. A success story from RPCAU notes that **"use of quality seeds alone can enhance crop productivity by 15–25%"**, and attributes Bihar's productivity constraints largely to its low SRR. By enabling farmers to produce certified seed themselves, such participatory schemes directly increase the local SRR and incomes. RPCAU also formed or supported Farmer Producer Organizations to aggregate small farmers for seed marketing and to leverage economies of scale. Research projects at RPCAU further institutionalize this approach. For instance, RPCAU lists a project titled **"Participatory Seed Production Program of Hybrid Paddy"** (with extension staff as PIs). This indicates a focus on bringing hybrid paddy seed (which inherently requires annual replacement) into Bihar's rice belts via farmer participation. In practice, RPCAU's seed and extension personnel helped identify lead farmers, supplied foundation seed, and certified the resulting crops. Such innovations bridge the gap between public breeding programs and farmer demand, making high-quality seed more accessible at the village level. Overall, RPCAU's

model blends top-down and bottom-up methods: it develops or procures seed material (often from ICAR institutes), then decentralizes production through community channels. Institutional innovations like village seed hubs and FPO collaborations are integral. As a result, awareness of certified seed benefits has spread in the region, helping to **increase adoption rates** and social acceptance of quality seed.

Infrastructure and Value Addition

Robust infrastructure underpins RPCAU's seed initiatives. The Dholi Directorate's seed processing plants (shown below) illustrate this commitment. Each unit uses **automatic cleaning, weighing, and bagging machines** to process raw seed into market-ready packets. Operators in the plant monitor output to maintain purity and viability. This mechanization both speeds processing and improves quality consistency, allowing large volumes of certified seed (rice, wheat, pulses, etc.) to be prepared each season without delays. After processing, certified seed is stored in clean, secure warehouses. Such stockpiling is critical to meet sowing-season demand. The DoS also maintains *seed storage godowns* at multiple sale points (e.g., Krishi Seva Kendras). This end-to-end value chain – from breeder seed storage to packaging of consumer seed – adds value by preserving seed quality and providing traceability. Each packet of Rajendra Pusa Beej includes variety and purity information, giving farmers confidence in its pedigree. In effect, RPCAU's infrastructure investments (processing plants, labs, storage) complement its outreach programs, ensuring that when farmers demand quality seed, it is available and reliable.

Impact Assessment

RPCAU tracks the outcomes of its seed interventions, though rigorous impact studies are still emerging. Anecdotally, villages participating in RPCAU's seed programs report higher yields and incomes. For example, farmers using RPCAU-certified seed noted yield increases in line with the expected 15–25% boost. In Bihar's flood-prone regions, the timely distribution of quality paddy seed helped farmers recover yield potential. More broadly, the SRR and cropping patterns in RPCAU's project areas have shifted: improved variety adoption (e.g., Zn-biofortified wheat, high-yield rice) is higher than district averages, reflecting the aggressive seed push. At the macro level, official data show that states where universities and agencies have raised SRR tend to have better production growth. In line with this, recent Rajya Sabha reports note that states proactively implementing seed plans and subsidies (like Bihar under the Mukhyamantri Seed Yojana) saw measurable SRR gains in key crops. While RPCAU's efforts

focus on Bihar, they contribute to national goals: by improving SRR even in one state, the programs indirectly enhance national food security. (For context, Indian Punjab's high SRR in wheat and rice underpins its grain surplus and rural prosperity; Bihar's rising SRR promises similar gains). In sum, **RPCAU's experience indicates that raising SRR delivers tangible benefits**. Certified seed use under the Rajendra Pusa Beej program is associated with higher productivity and more stable harvests for participating farmers. This underscores the broader evidence that every 10% increase in SRR can substantially boost aggregate food output.

Challenges

Despite progress, significant obstacles to raising SRR remain:

- **Supply-Demand Gap:** In many crops and regions, certified seed production still falls short of demand. Bihar, for example, imports seed from outside for several crops. (At the national scale, about 85% of farm-saved seed use implies persistent shortfalls in seed availability.)
- **Farmer Reluctance:** Many smallholders are risk-averse and default to saving seed from their previous crop, especially when new seed prices are high. Upfront cost and lack of immediate awareness can dampen adoption of certified seed, even when it offers 15–25% yield gains.
- **Awareness and Extension:** In remote areas, knowledge of seed benefits is still low. Without active extension or demonstrations, farmers may not perceive the long-term gains of SRR.
- **Infrastructure Weaknesses:** Outside RPCAU's network, many districts lack processing and storage. Poor roads and cold chains can delay seed delivery, forcing farmers to sow own seed or open-market grain (often of unknown quality).
- **Regulatory/Institutional Hurdles:** Delays in variety approval or uneven enforcement of seed laws can undermine confidence. Adulteration and counterfeit seed in some markets erode trust in "certified" labels.
- **Environmental Stress:** Floods, droughts and pests can destroy local seed stocks, making farmers cling to old seed. Climate uncertainties also make farmers cautious about trying new varieties or hybrids.

These challenges mean that even a rational seed program can stall. Overcoming them will require continued effort: more seed farms, stronger FPO networks, targeted subsidies (e.g. seed coupons for smallholders), and social marketing to shift mindsets. Addressing these constraints is the frontier for further raising SRR and, by extension, food and nutritional security.

Conclusion

The Seed Replacement Rate is a powerful indicator – and driver – of agricultural development. Rationally boosting SRR unleashes the genetic gains of modern crop varieties, underpinning higher yields, incomes, and nutritional outcomes. India's case (with SRRs still in the teens for staples) shows great untapped potential. The RPCAU (Pusa) example illustrates one successful model: a university-led seed system that combines quality genetics, community participation, infrastructure, and branding (*Rajendra Pusa Beej*). Through participatory production, modern processing plants, and active extension, RPCAU has begun to move the needle on SRR in Bihar. Scaling such integrated approaches – along with supportive policies like SMSP – can help meet national food security goals. In summary, bridging the gap between India's large seed market and its low SRR will require technical, institutional, and educational investments. When farmers routinely use fresh certified seed (targeting 20–30% SRR or more in key crops), the nation can expect a step change in productivity and nutrition levels.

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Attaining Nutritional Security through Diet Diversity: Insights through Multistakeholder Project of RPCAU

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Abstract

This chapter examines the critical shift required to effectively combat global hunger and malnutrition in the 21st century. While decades of effort have largely addressed the issue of food security—ensuring the availability of sufficient calories—a persistent paradox of malnutrition, or "hidden hunger," continues to affect billions. This abstract posits that a fundamental change in focus from a quantitative approach to a qualitative one is necessary. It argues for the transition from food security (access to enough food) to nutrition security (access to a diverse, nutrient-rich diet with the physiological ability to utilize it). Through a comprehensive analysis of sustainable agricultural practices, policy frameworks, and technological innovations, this work explores actionable strategies to create resilient food systems that prioritize not just quantity but the nutritional quality of food for all. Ultimately, this chapter presents a roadmap for a future where a full stomach is synonymous with a healthy body and mind.

Keywords*:* Food Security, Nutrition Security, Global Hunger Index (GHI), Malnutrition, Hidden Hunger, Micronutrient Deficiency, Biofortification, Dietary Diversity

Introduction

In today's interconnected world, achieving food and nutrition security for all people remains a central challenge, despite significant advancements in agricultural science and technology. This complex issue goes beyond simply producing enough food; it encompasses ensuring that every

individual has consistent access to a sufficient quantity of safe, affordable, and nutritious food to lead a healthy and active life. While progress has been made in reducing global hunger, a variety of modern challenges—including climate change, political instability, and economic inequality—threaten to reverse these gains and underscore the critical need for comprehensive strategies that address both food supply and dietary quality.

Key concepts

- **Food security** is the state where all people have consistent, reliable access to enough safe and nutritious food to lead a healthy and active life. This concept is traditionally defined by four key pillars: availability, ensuring a sufficient quantity of food is produced and supplied; access, making sure people can acquire food physically and economically; utilization, ensuring the body can properly absorb nutrients through good sanitation and health; and stability, ensuring access to food remains consistent over time, even during shocks like economic crises or natural disasters. Essentially, it's about whether there is enough food for everyone and whether they can get it.
- **Nutrition security** is a more comprehensive concept that goes beyond food security. It exists when all people not only have access to enough food, but also to a diverse diet rich in essential macronutrients (proteins, fats, carbs) and micronutrients (vitamins, minerals), along with a sanitary environment and adequate health care. One can be food secure—having enough calories to fill your stomach—yet be nutritionally insecure due to a poor diet lacking vitamins, which can lead to conditions like anemia. In essence, while food security is about quantity, nutrition security is about the quality of the food and the body's ability to use it effectively.
- **Global hunger** remains a critical and complex challenge, driven by a combination of factors including conflict, climate change, and economic instability. While global hunger has seen some decline in recent years, this progress is not uniform and has stagnated in many regions. As of the most recent reports, an estimated 673 million people faced hunger in 2024.
- "**Hidden hunger**," also known as micronutrient deficiency, is a form of undernutrition that occurs when a person's diet lacks the essential vitamins and minerals needed for proper health and development. Unlike traditional hunger, which is characterized by a lack of calories, hidden hunger often goes unnoticed because the individual may be consuming enough food to feel full, but the food is of poor quality and lacks vital nutrients.

1. Agriculture Scenario in India

India with a long history of agriculture has been the backbone of economy for ages. Agriculture has been originated in India in Neolithic age. Yet it remains a critical sector even today, contributing 18.3 per cent to India's Gross Value Added (GVA) in 2022–23, as per the Ministry of Agriculture and Farmers' Welfare. Historically, India has been a country essentially based on cereals, pulses and fruits vegetables and sugarcane with other food articles playing relatively minor roles. In the meantime, the country has diversified its attention to issues involving oilseeds, honey production and even mushroom farming — an indication of a move towards agricultural diversification in recent years. Yet, behind this story of progress, another one runs quietly. Children under five, many of them, are weak and malnourished. Some are too short for their age (stunting). Some are dangerously thin (wasting). Lack of iron and other micronutrients makes them pale, tired, slow to grow. It's not just biology—it's poverty, floods, droughts, poor storage of crops, lack of awareness, food that doesn't reach the right mouths. These little gaps in nutrition turn into bigger problems later in life. Heart disease, diabetes, lifestyle illnesses—silent burdens that keep piling up. India isn't alone and many countries in Africa, Asia, Latin America face the same. Now imagine this chain. A farmer grows more; a family earns better. A mother buys vegetables, pulses, eggs. The child eats well, plays more, learns faster. Nutrition isn't only about food—it's about life itself. A sustainable food chain means health, energy, growth. Agriculture drives it. The more diverse our farms, the more balanced our plates. On global map, bright red patches across Africa and South Asia can be seen. These showed places where Vitamin A, Iron, and Zinc deficiencies were the worst among children under five. Yellow patches in developed countries looked almost calm, like hunger was someone else's problem. However, in India, Pakistan, Afghanistan, even Indonesia—the red spread wide. The World Health Organization called it "hidden hunger." Hidden, because you don't always see it right away but it cripples growth, Minds, future. Food should fix this, right? After all, food is the fuel. It gives us energy, repairs our tissues, keeps the body machine running but food alone is not always enough. Malnutrition takes many shapes. Sometimes it's too little food—undernutrition. Sometimes it's the wrong kind—too much fat, sugar, junk—overnutrition. Both are dangerous and both are spreading. Malnutrition isn't just about eating. It's about three things. First—*availability*. Is there enough food around? Second—*accessibility*. Can families actually afford and reach it? And third—*utilization*. Does the body use it properly? Safe water, sanitation, and knowledge about cooking or feeding play a role here too. A house can have rice stacked in the kitchen, but without clean water or vegetables, the meal still fails to nourish.

Balanced nutrition—that's the goal. Carbohydrates, proteins, fats, vitamins, minerals. Each in the right measure. Sounds simple, but it isn't. The world knows this. The UN has put it as one of their boldest missions—"Zero Hunger". By 2030, no one should sleep hungry. No child should suffer from malnutrition.

Staple foods help to keep people alive. They are easy to store, cheap and eaten daily. Rice in Bengal, wheat in Punjab, potatoes in Bihar, cassava in Africa are few examples of staple foods. Staples alone cannot give everything. That's why families also need "other foods"—milk, vegetables, fruits, nuts, meat, eggs. Food comes to us in three ways. We *grow* it ourselves; we *get* it from markets or sometimes, it is *given*—through donations, aid, or food banks. The mix of all three decides what ends up on the plate. Just think that the body is like a car. It won't move without fuel. Same for us. For daily energy, we burn carbohydrates and fats. For strength and repair, we need protein. They are known as energy yielding and body building foods. On the other hand, fruits and vegetables are called protective foods. They are packed with vitamins, minerals, fiber, and magical compounds like antioxidants and phytochemicals. Together, they guard the body, keep diseases away and build strength inside out. Think vitamins first – vitamin A for eyesight, vitamin C for immunity, vitamin E for skin, vitamin K for blood and folate for growth. Then minerals like potassium, magnesium, iron, zinc help in bone growth, nerves function, and the immune system to fight back. Antioxidants and phytochemicals are silent warriors as they stop free radicals from damaging. In India, the government knows the stakes. That's why the "Integrated Child Development Services (ICDS)" exists. Anganwadi Centres are everywhere—in villages, in towns. They give children food, vaccinations, pre-school lessons. They teach mothers about health, about feeding and link up with other programs like the *Swachh Bharat Mission* for sanitation and the National Rural Health Mission for healthcare. At the grassroots, it is these small interventions that stop a child from slipping into malnutrition.

2. Diet Diversification

Diet diversification is the way in which different types of vegetables and fruits are used as much as possible in our daily diet. This ensures intake of proper balanced meal daily, reducing the risks of deficiencies and malnutrition. Enhancement in diet diversification is done by:

a) **Adolescent Nutrition:** Adolescents are the main focus. Here, teenagers are learning what to eat, and why. Training programs roll out and the Education Department steps in. JEEVIKA groups get stronger with new skills and get more food choices which more nutritious and better for health.

b) **Severe Acute Malnutrition (SAM) and Moderate Acute Malnutrition (MAM) Children:** Children battling Severe and Moderate Acute Malnutrition are the weakest. The strategy to eradicate the malnutrition by keeping it close to home, use home-based foods, simple, local and powerful, (working with ICDS guided by *Poshan Abhiyaan)*

c) **The First 1000 Days:** It refers to the crucial 24 months between conception and the child's second birthday, when the child's brain develops quickly and their intelligence and health are significantly influenced for the rest of their lives. The message is simple: what happens this period shapes a lifetime. Nutrition here means stronger bodies, sharper minds, healthier futures. Miss it—and the chance is gone.

In Sitamarhi, Severe Acute Malnutrition in children under five is tackled through a community-based strategy. Anganwadi workers screen and detect cases—complicated ones go to facilities; uncomplicated ones get home care. Treatment relies on Ready-to-Use Therapeutic Food (RUTF) or local nutrient-dense foods. Community mobilization, health worker training, and strict monitoring ensure recovery and behaviour change. The approach follows POSHAN Abhiyaan—bringing care home, one child at a time.

3. Nutrition Garden

Nutrition garden different from the regular kitchen garden your grandmother might have kept. This one is structured, a bit more thoughtful. The crops are chosen carefully- season by season; so, there's always something to harvest, something to put on the plate and something the body actually needs.

Advantages of Nutrition Garden:

- It ensures a varied, nutritious diet season by season
- It provides chemical-free food
- It cuts the food costs
- It gives better taste and better quality
- It ensures food security
- It reduces Wastes by reuse

Table 1: Different Fruits and Vegetables for Nutrition Garden in different seasons

Ravi season (November to March)		
Cabbage	Coriander	Fenugreek
Cauliflower	Brinjal	Radish
Tomato	Beans	Carrot
Red greens	Spinach	Patua
Amla	Drumstick	
Summer (April to June)		
Bottle gourd	Spinach	Ladyfinger
Large ridge gourd	Brinjal	Kidney beans
Bitter gourd	Beetroot	Cucumber
Lettuce		
Kharif (July to October)		
Spinach	Kidney beans	Chilly
Tomato	Turmeric	Ginger
Ladyfinger	Ridge gourd	Onion
Fruits		
Papaya	Lemon	Amla
Guava	Raspberries	Cranberry
Henna	Curry leaves	Banana

4. Ankuran Project in Bihar

Bihar is going green. The Education Department has rolled out the *Ankuran* project over 70,000 government schools will soon have kitchen gardens. The idea is simple; kids from standard I TO VIII will grow seasonal vegetables and some fruits too through organic farming. It's not

just farming. It's nutrition and supplement of the Mid-day meal scheme in India. It promotes food diversity and it is about teaching children about sustainable agriculture. Teachers will guide students, with support from the agriculture department, KVKs, universities, UNICEF, and other agencies. Similar school farming programs are also being introduced in states like Uttar Pradesh, Punjab, Andhra Pradesh, Kerala, and Gujarat.

5. The space management in gardening

Space is precious. Especially in cities. But where there's a wall, a roof, or even a patch of land—there's room for green.

a) **Vertical Gardening:** Imagine a wall that breathes. Rows of small pockets, each bursting with plants. Herbs, flowers, maybe even vegetables. Vertical gardens turn plain walls into living, growing spaces. Perfect for cities where ground space is tight. They clean the air, cool the surroundings, and look stunning too.

b) **Rooftop Greenery:** Now picture a roof that grows. Not just tiles or tin, but grass, creepers, or vegetables covering the top. A living roof. It keeps the house cool in summer, warm in winter, and beautiful all year round. For some, it even doubles as a small farm. Sustainability meets design.

c) **Field Cultivation:** And of course, the classic—fields. Crops planted neatly, rows upon rows, each inch of soil used wisely. Traditional, yes. But still the backbone of food production. Organized layouts and planned spacing mean higher yields, healthier crops, and less waste.

Whether it's walls, rooftops, or fields—space management is creativity in action. It's about using every inch smartly utilised for food, beauty and life.

Marginal farmers in space management

Then, there are farmers especially *marginal ones*. Owning less than one hectare of land, often buried in debt, sometimes working as labourers on other people's fields. For them, survival itself is farming but new ideas are sprouting—literally rooftop gardens, container gardening, two-tier, and even three-tier systems of planting. Using pots, grow bags, recycled buckets, tiny spaces turning into mini-farms. Imagine a family in a crowded city growing spinach on the roof, tomatoes in old paint buckets and fresh, organic food for themselves. A little extra income from selling the surplus. Urban food security, one balcony at a time. It is about the plate of a

child. About whether that plate has rice alone, or rice with vegetables, lentils, and maybe a boiled egg. That one difference decides futures.

6. India's Global Hunger Index (GHI) Performance

The Global Hunger Index (GHI) is an annual report that ranks countries based on four key indicators to measure hunger and undernutrition. According to the 2024 Global Hunger Index, India ranks 105th out of 127 countries, placing it in the "serious" category of hunger. India's GHI score for 2024 is 27.3, which, while a slight improvement from past years, is still considered a high level of hunger.

The GHI score is calculated using four indicators:

- **Undernourishment:** The share of the population with insufficient caloric intake.
- **Child Wasting:** The percentage of children under five who have a low weight for their height, reflecting acute undernutrition.
- **Child Stunting:** The percentage of children under five who have a low height for their age, reflecting chronic undernutrition.
- **Child Mortality:** The death rate of children under five, partly reflecting the effects of malnutrition.

Despite the debates, India's high child wasting rate, at 18.7 percent, remains a major concern and is one of the highest in the world, as highlighted by the report. The country has, however, shown significant improvements in other indicators, such as a decline in child mortality. India has largely achieved food security in terms of availability. Following the Green Revolution, the country has become a net exporter of food grains, with record production of crops like rice and wheat. This success is supported by robust policies like the National Food Security Act (NFSA), 2013, which provides a legal entitlement to subsidized food grains for over two-thirds of the population. Through the Public Distribution System (PDS), millions of households receive essential grains at highly subsidized prices. This extensive network has been critical in preventing widespread starvation and ensuring a basic level of food access, especially for the most vulnerable. Despite strides in food availability, India's performance on nutrition security remains a major challenge. Data from the National Family Health Survey (NFHS-5) (2019-21) shows that while there have been improvements, the rates of malnutrition are still a significant concern.

- **Child Stunting:** Around **35.5%** of children under five are stunted (low height for their age), a sign of chronic undernutrition.
- **Child Wasting: 19.3%** of children under five are wasted (low weight for their height), indicating severe, acute malnutrition. This is one of the highest rates globally.
- **Anemia:** Anemia is widespread, affecting over 57% of women aged 15-49 and 67% of children under five.

To combat this, the government has launched flagship programs like the POSHAN Abhiyaan (National Nutrition Mission), which uses a multi-sectoral approach to address malnutrition through a combination of technology, behavioral change, and targeted interventions for women and children.

7. Role of Dr. Rajendra Prasad Central Agricultural University

Dr. Rajendra Prasad Central Agricultural University (RPCAU) plays a multi-faceted and pivotal role in addressing the issues of food and nutrition security, particularly in the socio-economically challenged and climate-vulnerable regions of Eastern India. Its efforts span from high-level genetic research to on-the-ground farmer training, aiming to create a more resilient and productive agricultural system.

8. Enhancing Food Security through Agricultural Innovation

RPCAU's primary role in food security is to develop and disseminate agricultural technologies that boost productivity and resilience. The university's research has led to the release of over 60 new crop varieties that are high-yielding and resilient to various stresses. For instance, it has developed climate-resilient cultivars of rice, maize, and pulses that can withstand floods, droughts, and heat stress, directly helping farmers mitigate the impacts of climate change on their livelihoods and food supply. RPCAU also works on developing resource-efficient farming methods, such as precision agriculture and practices for effective soil and water management, which are crucial for sustainable food production in a resource-scarce environment.

9. Combating Malnutrition through Nutrition-Focused Research

Beyond just producing more food, RPCAU focuses on improving its nutritional quality to combat malnutrition. The university's College of Community Science is at the forefront of this effort, conducting research on biofortification and the development of nutrient-rich food products. This includes developing new varieties of crops with enhanced levels of vitamins and

minerals, as well as creating value-added food products from local, traditional crops like millets. This work directly addresses "hidden hunger" by providing more nutritious alternatives to staple grains. The following are the interventions to combat the issue of food and nutrition insecurity:

- **Nutritional Product Development:** It has been instrumental in developing new food products with enhanced nutritional value, particularly those based on local, traditional crops like millets and quality protein maize. The developed food formulations to combat anemia and malnutrition, with a special focus on children, adolescents, and pregnant women is the main focus. One of the patented innovations includes an "Energy Dense Nutritive Food" with a balanced nutritional composition.
- **Technology and Innovation:** There have been different granted patents for devices that reduce the drudgery of food processing for women, such as a "Hand Cranked Improved Chakki" for grinding grains and a power-driven device for shelling and hulling. These innovations make food preparation more efficient and less labor-intensive for rural communities.
- **Research and Advocacy:** The research explores the link between agriculture, food science, and nutrition. There have been publications extensively on topics such as food processing, food waste minimization, and the role of maize in human nutrition. The collaboration on large-scale projects like the "Swabhimann" program, an integrated multi-sectoral strategy to improve girls' and women's nutrition in several Indian states is a great step towards mitigating global hunger.

10. Interventions done by RPCAU to mitigate global hunger

This chapter explores how a multi-stakeholder project led by RPCAU (Dr. Rajendra Prasad Central Agricultural University) addresses the persistent challenge of malnutrition in India. It highlights a comprehensive strategy that combines dietary diversification, technological innovation, and women's empowerment to achieve food and nutritional security, particularly for vulnerable groups like children and women. The initiative aims to shift the focus from merely ensuring food availability to improving the accessibility and utilization of nutrient-rich foods at the household level through a series of interconnected interventions.

11. India's Nutritional Challenges

Despite significant food production, India faces a serious issue of malnutrition. The country has enough food, yet many people remain malnourished due to poor accessibility and utilization of a balanced diet. According to data from the CNNS (Comprehensive National Nutrition Survey) from 2016-2018, 42.0% of children under five years old suffer from stunting, and 14.5% suffer from wasting. The burden of severe stunting and wasting affects millions of children. Micronutrient deficiencies are also a major concern, with a high prevalence of anaemia (43.9%), vitamin A deficiency (23.5%), and zinc deficiency (19.8%) among children aged 1-4 in Bihar. These deficiencies are linked to lifestyle and degenerative diseases, and they are particularly exacerbated in disaster-prone areas and among populations with a lack of awareness and poor post-harvest management practices.

12. Empowering Women through Home-Based Nutrition

The project has demonstrated success in empowering women and improving child nutrition, particularly through collaborations with government departments and community groups. The Poshan Abhiyan initiative, for example, focuses on home-based nutritional therapy for children with Severe Acute Malnutrition (SAM) in places like Sitamarhi, Bihar. Caregivers are trained in proper screening, referral, and food demonstration to combat malnutrition. They learn to prepare a variety of energy-dense, nutritious foods using local and readily available ingredients. This intervention has led to a significant reduction in the prevalence of SAM among children in the area.

Table 2: List of ingredients prepared by women at Sitamarhi households

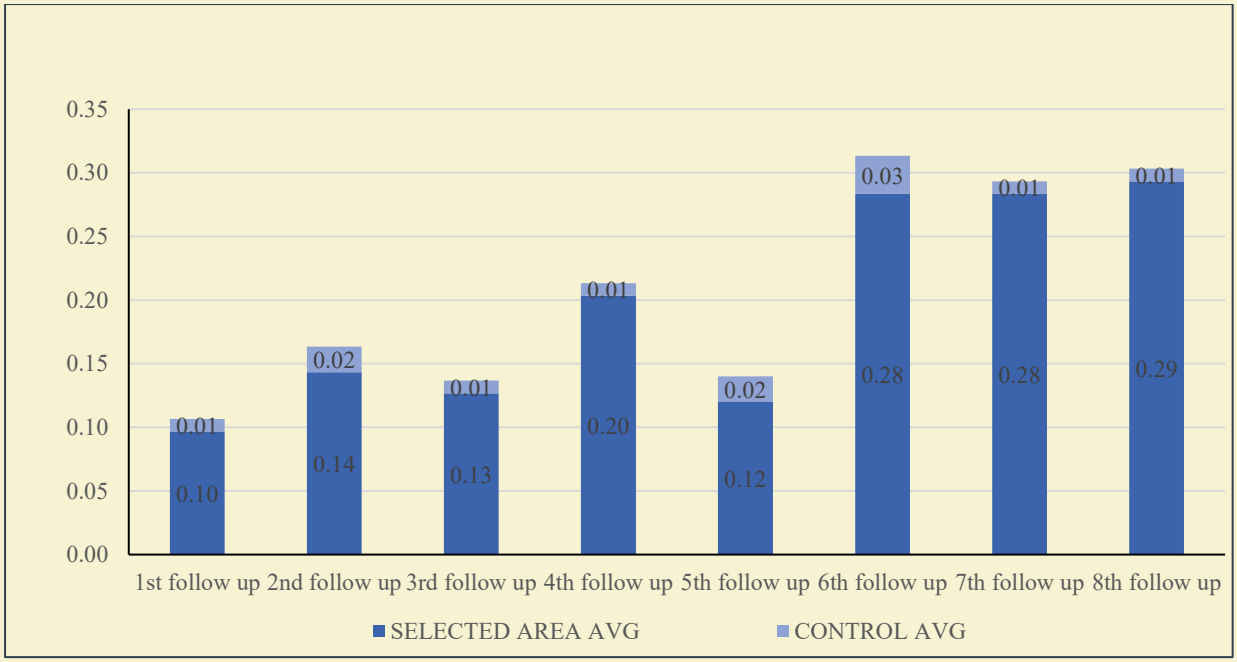
S.No.	Recipe	Ingredients
1	Veg rich namkin chila	Mixed flour + Dal + green leafy veg + onion + Tomato + oil
2	Paushtik Laddoo	Wheat flour + Sattu + ground nut + sesame seed + refined oil + milk powder + jaggery
3	Sattu Laddoo	Sattu + ghee + jiggery + groundnut
4	Soyabean Khichri	Rice + Pulse + Soyabean + veg + saag + salt + turmeric
5	Bottle-gourd Kheer	Rice + Bottle gourd + Milk + Ground nut + Sugar

6	Sweet chila	Wheat flour + milk + sesame seeds + groundnut + banana + Jaggery + oil
7	Dalpithhi	Dal + Spinach + wheat flour (tomato, oil, cumin seeds for seasoning)
8	Halwa	Semolina + ghee + groundnut + sugar + milk powder + water
9	Gola Roti	Wheat flour + Gram flour + Drumstick leaves + oil + salt + water
10	Aaloo Paratha	Wheat Flour + Aloo + less spices + oil
11	Health mix	Germinated wheat + soaked moong dal + groundnut + milk powder + sugar
12	Thhekua	Multigrain flour (Wheat, ragi, moong dal) + Jaggery + ground nut + Refined oil
13	Veg mixed omelette	Egg + vegetable (tomato, onion, coriander leaves) + oil + salt
14	Veg Pakoda	Saag + Onion + gram flour + rice flour + oil + turmeric + salt

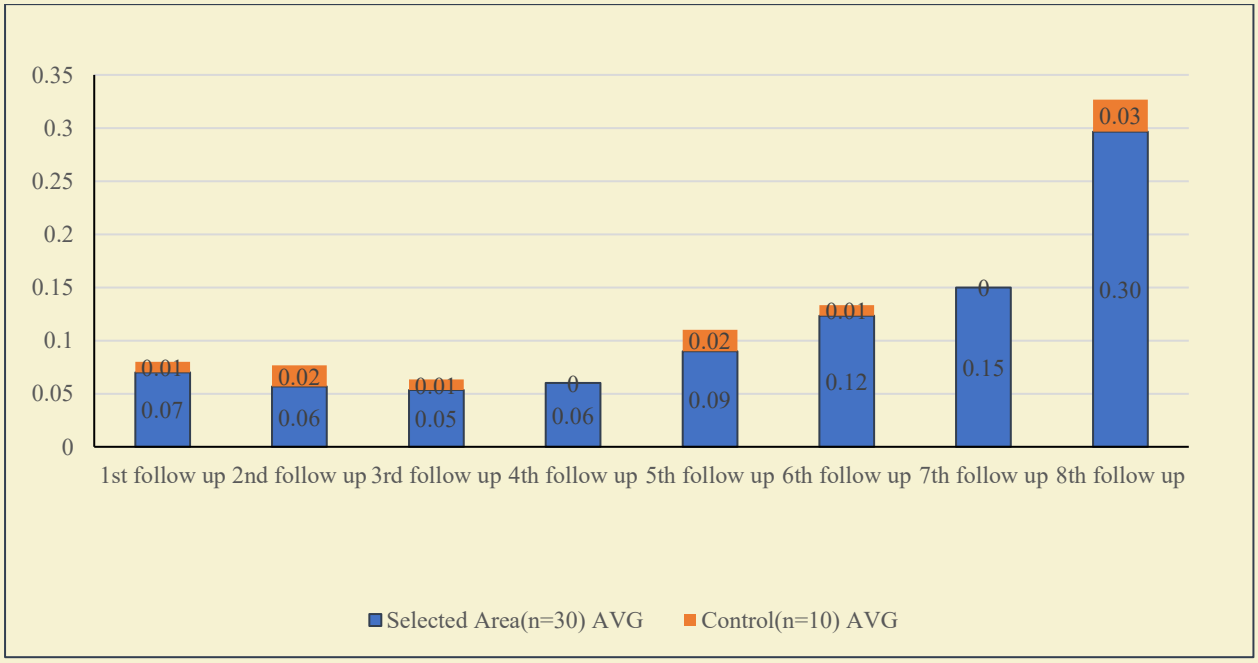
13. Scaling Nutrition Interventions in Bihar: The ICDS and RPCAU Model

The ICDS in Bihar has taken steps to scale up this initiative by providing ready-to-eat (RTE) food and conducting capacity-building training for its field functionaries. The results from the Sitamarhi & Begusarai districts of Bihar intervention showed a significant reduction in the percentage of children with SAM:

- **November 2019:** 5.42% of screened children were SAM.
- **February 2020:** The percentage dropped to 3.37%.
- **September 2020:** The percentage further decreased to 0.14%.



a) Sitamarhi (N=40)



b) Begusarai (N=40)

Fig.1. Weight gain (Kg) among enrolled and non-enrolled children

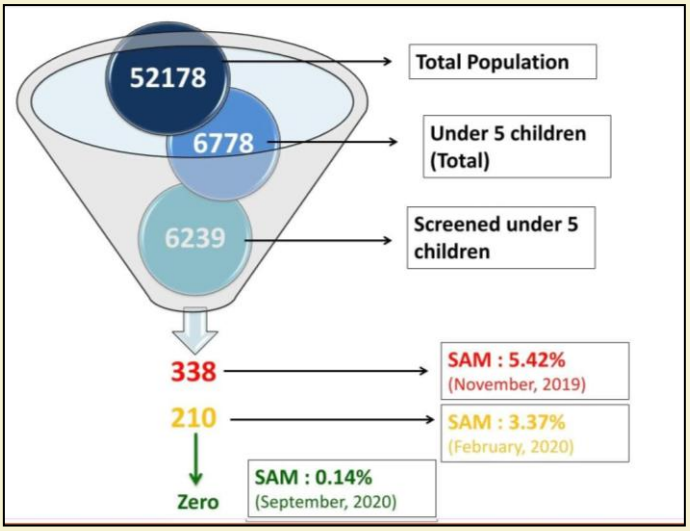


Fig.2. Size of population affected by intervention on SAM

The Government of Bihar's Integrated Child Development Services (ICDS) Directorate is actively engaged in scaling up its nutritional interventions to combat malnutrition. A key strategic move is the provision of Hot Cooked Meals (HCM), also referred to as Energy-Dense Nutritional Food (EDNF), under the Supplementary Nutrition Programme (SNP). To ensure a robust supply chain, the ICDS Directorate is inviting Expressions of Interest (EOI) from registered non-governmental organizations (NGOs), Self-Help Groups (SHGs), and other agencies to supply hot cooked meals such as Paushtik Laddoo, Sattu Laddoo, and Baalbhog to children aged 3 to 6 years at Anganwadi Centers (AWCs).

In addition to procurement, the ICDS Directorate has implemented extensive capacity-building and training initiatives to support this scale-up. These efforts include:

- **State-level meetings** with District Program Officers (DPOs), Krishi Vigyan Kendra (KVK) scientists, ICDS officials, and development partners.
- **District-level meetings** with Child Development Project Officers (CDPOs).
- Training sessions for all female supervisors across Bihar via Zoom and for Anganwadi Workers (AWWs) via YouTube Live.

These training sessions and initiatives primarily focus on promoting the preparation of nutritious and easy-to-make meals like Khichadi and Cheela at the local level. The collaboration between the government, academic institutions like RPCAU, and local self-help groups is instrumental in ensuring these nutritional interventions are effective and sustainable.

The key products that have been scaled up include:

- **Paushtik Laddoo**: A nutrient-rich sweet ball.
- **Sattu Laddoo**: A protein-rich sweet ball made from roasted gram flour.
- **Balahaar**: A ready-to-use food product for children above six months, composed of wheat, green gram, ghee, milk powder, and sugar.
- **Khichadi**: A traditional meal of rice and lentils.
- **Cheela**: A type of savory pancake.

These products are part of a model that emphasizes auto-dissemination and self-entrepreneurship. The "Nari Shakti JEEViKA Balahaar Utpadak Samooh," a producer group of 20 JEEViKA Didi's, is now producing Balahaar on a commercial scale. The product has been developed by RPCAU and is now available in the market. This initiative highlights a successful collaboration between a government department, a university, and local community groups to address nutritional needs and promote local entrepreneurship. Balahaar is a ready-to-use food product recommended for children above 6 months.

- ❖ **Composition:** Wheat, Green gram, Ghee, Milk powder, and Sugar
- ❖ **Method of use:** It can be mixed thoroughly with hot water or milk before use.
- ❖ **Training:** The training has been provided to a group of 20 JEEViKA Didi's (group formed under NRLM), from the poorest to the poorest women**.**
- ❖ **Production:** This producer group training is producing Balahaar on a commercial scale, and now product is in marketed by "Nari Shakti JEEViKA Balahaar Utpadak Samooh".

13.1 Enhancement in Balahaar production

It shows the production in kilograms from December 2022 to June 2023. Production started with 36 kg in December 2022, dropped to 0 kg in January 2023, and then rose steadily from February to June 2023. By June 2023, production had reached 170 kg. This significant increase demonstrates the successful scaling up of the initiative. Table 3 details the nutritional composition of the Balahaar product. It has an energy value of 386 Kcal, 19.0g of protein, and 17.6g of total fat. The protein provides 4.92g per 100 Kcal, and the fat constitutes 41% of the total calories. The product contains 15% sugar, which is within the permissible limit. It also contains 174mg of Calcium and 4.54mg of Iron. These nutritional facts highlight its value as a food source.

Table 3: Nutritional value of balahaar

Parameter	**Results**	**Implications**
Energy (Kcal)	386	
Protein (g)	19.0	4.92g/ 100 KCal
Total Fat (g)	17.6	41% of the total calorie
Sugar (%)	15	permissible limit
Calcium (mg)	174	
Iron (mg)	4.54	

13.2 "**Balahar for Infants (6-12 months)**" details the product's nutritional adequacy for this age group. Table 4 shows that for infants aged 6 to 12 months, a 50-gram serving of Balahar provides 9.5 grams of protein, fulfilling 57.93% of their daily protein needs. It also supplies 193 Kcal of energy, meeting 24.61% of their daily requirement, and 87 mg of calcium, which is 17.40% of their daily need.

Table 4: Nutritional adequacy of Balahar for infants

Nutrient	Daily Requirement	Provided by 50 g Balahar	% of Requirement Met
Protein (g)	16.4 g	9.5 g	57.93%
Energy (Kcal)	784 Kcal	193 Kcal	24.61%
Calcium (mg)	500 mg	87 mg	17.40%

13.3 "Balahar for children (1 to 3 years)" For this group, a 100-gram serving of Balahar provides 19.0 grams of protein, satisfying 86.36% of their daily needs. The serving also contains 17.6 grams of total fat (70.40% of the daily requirement) and 386 Kcal of energy (31.13% of the daily requirement). Additionally, it provides 174 mg of calcium (43.50% of the daily need) and 4.54 mg of iron (37.83% of the daily need). This information demonstrates Balahar's effectiveness in providing essential nutrients to combat malnutrition in young children.

Table 5: Nutritive adequacy of balahar for children

Nutrient	Daily Requirement	Provided by 100 g Balahar	% of Requirement Met
Protein (g)	22 g	19.0 g	86.36%
Energy (Kcal)	1240 Kcal	386 Kcal	31.13%
Fat (g)	25 g	17.6 g	70.40%
Calcium (mg)	400 mg	174 mg	43.50%
Iron (mg)	12 mg	4.54 mg	37.83%

14. Biofortification – Options for Better Nutrition

Biofortification is an innovative and sustainable approach to address widespread micronutrient deficiencies by enhancing the nutritional quality of food crops through agricultural interventions. Unlike supplementation and fortification, which rely on external supply chains and continuous infrastructure support, biofortification is a seed-based solution that benefits communities in a cost-effective and long-term manner.

There are four major strategies to improve nutrition:

a) **Supplementation** – Distribution of vitamin and mineral tablets or syrups, though often limited by supply chain issues, compliance, and affordability.

b) **Commercial Fortification** – Adding nutrients to processed foods (e.g., iodized salt, fortified flour, or edible oils). While effective in urban areas, this requires organized infrastructure, consumer awareness, and regulatory monitoring.

c) **Dietary Diversity** – Promoting balanced diets with locally available fruits, vegetables, pulses, and animal products. Though ideal, it is constrained by poverty, seasonal availability, and limited access.

d) **Agricultural Intervention through Biofortification** – Development of crops naturally rich in micronutrients through conventional breeding, molecular breeding, and genetic engineering. Being a farmer-led and seed-based approach, it ensures sustainability.

Advantages of Biofortification:

- Targets staple foods like rice, wheat, maize, pearl millet, and lentils that are widely consumed.

- Improves intake of critical micronutrients such as iron, zinc, vitamin A, and quality protein without requiring major changes in dietary habits.
- Provides a cost-effective and scalable solution for rural and low-income populations.
- Enhances the biological value of diets, particularly benefiting women and children who are most vulnerable to hidden hunger.

14.1 Examples of Biofortified Crops in India:

- **Rice & Wheat** enriched with zinc and iron.
- **Quality Protein Maize (QPM)** with a superior amino acid profile and higher biological value compared to normal maize.
- **Pearl Millet** enriched with iron and zinc.
- **Sweet Potato & Mustard** biofortified with vitamin A.
- **Lentil & Cauliflower** with enhanced micronutrient content.

Biofortification, when combined with awareness generation and effective distribution, has the potential to significantly reduce hidden hunger, improve immunity, and enhance long-term nutritional security at the community and national levels.

14.2 Biofortified Crops: A Pathway to Nutritional Security

Biofortification has emerged as a sustainable agricultural intervention to tackle hidden hunger by enriching staple crops with essential micronutrients. This strategy leverages both conventional plant breeding and modern biotechnological tools to develop nutrient-dense varieties that directly reach vulnerable populations through regular diets.

14.3 Role of Research Institutions & Partnerships

- State Agricultural Universities (SAUs), ICAR institutions, and international organizations such as CIMMYT (International Maize and Wheat Improvement Center) and IRRI (International Rice Research Institute) are key partners.
- Collaborative projects have accelerated the development and dissemination of biofortified varieties suited to local agro-climatic conditions.

14.4 Major Biofortified Crops:

- **Cereals:**
    - Rice and Wheat enriched with zinc and iron.
    - Maize with enhanced carotenoids, proteins, and fats (Quality Protein Maize).
    - Pearl Millet enriched with iron and zinc.
- **Other Crops:**
    - Lentils with higher iron and zinc.
    - Cauliflower with enhanced micronutrient profile.

- Sweet Potato biofortified with vitamin A.
- Mustard is rich in essential micronutrients.
- Pomegranate with improved antioxidant potential.

14.5 Impact on Nutrition:

- Increased availability of iron, zinc, vitamin A, and quality proteins in commonly consumed staples.
- Improves the biological value of diets without altering food habits.
- Particularly beneficial for children, adolescents, and women, where deficiencies are most common.

15. From Production to Consumption: Biofortification ensures that improvements begin at the seed level, continue through production and distribution, and reach consumers' plates, thereby bridging agricultural development with public health nutrition.

15.1 Nutritional Superiority of QPM

- **Balanced Protein Profile:** Contains a better ratio of essential amino acids, improving digestibility and utilization.
- **High Biological Value:** Ensures efficient protein absorption, reducing the risk of protein-energy malnutrition.
- **Health Benefits:** Helps address stunting, wasting, and undernutrition in rural communities where maize is a staple.
- **Sustainability:** As a seed-based intervention, it can be widely adopted by farmers without altering dietary habits.

16. Potential of Maize in Diet Diversification

Maize is not just a staple cereal but also a foundation for a wide range of nutritious and functional foods. When biofortified into QPM, its application broadens across age groups and socio-economic segments.

16.1 Maize Food Groups:

- **Cereal-based energy foods** for daily sustenance.
- **Protein-rich complementary foods** for infants and children.
- **Health foods** for vulnerable groups like women, the elderly, and the undernourished.

- **Snack & savory products** for all age groups.
- **Convenience foods & specialty products** suited to modern lifestyle

16.2 Value Addition through Maize

With biofortification and processing, maize transforms into diverse value-added products:

- **Complementary foods** for infants (QPM-based porridges, mixes).
- **Health mixes** for malnourished children and mothers.
- **Snacks and convenience foods** enriched with QPM.
- **Specialty products** targeted at stress management and immunity support.

This integration of QPM into food systems not only combats malnutrition but also creates livelihood opportunities through entrepreneurship and food processing industries.

17. Maize Products – From Nutrition to Business Models

QPM has tremendous potential to be processed into commercial products that ensure both nutritional security and income generation.

1. **For Infants & Young Children:** Complementary foods, fortified porridges, weaning mixes.
2. **For Vulnerable Groups:** Health mixes and energy-dense QPM-based foods.
3. **For General Population:** Snacks, savory items, bakery products, and convenience foods.
4. **For Industry:** Specialty and functional foods catering to lifestyle and health-conscious consumers.

Thus, QPM-based maize products serve a dual purpose:

1. Fighting hidden hunger and malnutrition.
2. Creating scalable business opportunities for SHGs, FPOs, and rural entrepreneurs.

18. Innovative Nutrition-Smart Agro-Processing Technologies Developed at RPCAU, Pusa

18.1 Rajendra Hand Cranked Chakki – A Farmer-Friendly Innovation

To promote nutrition-sensitive agriculture and reduce drudgery in food processing, RPCAU Pusa has developed the Rajendra Hand Cranked Chakki. This technology has been transferred to M/s Kishan Agro, Biharsarif (Bihar) under an MoU agreement, ensuring its availability at a commercial scale.

Key Features:

- **Reduced Drudgery**: Designed to be operated in a sitting posture, making it comfortable and user-friendly, particularly for women farmers.
- **High Capacity & Efficiency**: Capable of handling substantial quantities, suitable for cottage industry as well as small-scale commercial production.
- **Multi-Product Use**: Apart from producing dal, it can process *sattu, grits, dalia, and besan*.
- **Patent Protection**: *Design Patent (No. 342101-001), granted on 28.03.2022.*

Significance:

- Provides an affordable, locally adaptable technology that enhances post-harvest processing at the household and community level.
- Encourages self-reliance and entrepreneurship in rural areas, especially among women's groups and Self-Help Groups (SHGs).
- Supports the vision of linking agriculture with nutrition and livelihoods by ensuring value addition at the grassroots.

18.2 Electric Okhali – A Multi-Functional Grain Processing Innovation

The Electric Okhali is an innovative post-harvest technology developed by Dr. Rajendra Prasad Central Agricultural University, Pusa, designed to make small-scale grain processing efficient and user-friendly. This machine has been commercially transferred to M/s Binod Engineering, Bihiya (Bhojpur) for large-scale production and adoption.

a) Functions Performed:

- **Dehulling** – Removes husk from grains for easy processing.
- **Winnowing** – Separates husk, dust, and impurities.
- **Separation & Grading** – Ensures uniform quality of processed grains.

b) Technical Features:

- **Hopper Capacity**: 4–5 kg at a time, suitable for household and small-scale use.

- **Versatility:** Can process a wide range of grains, including *paddy, wheat, barnyard millet, foxtail millet, proso millet, oats, barley*, and even coarse spice powdering.
- **Patent Protection**: *Patent No. 417406, granted on 10.01.2023.*

c) Significance:

- Reduces manual effort and time in traditional grain processing.
- Provides cost-effective technology for rural households, SHGs, and small entrepreneurs.
- Ensures better grain quality, encouraging value addition and local-level food processing.
- Bridges the gap between traditional practices and modern efficiency, empowering farmers and rural women.

18.3 Energy-Dense Nutritive Food – A Ready-to-Eat Solution for Malnutrition

The Energy-Dense Nutritive Food (EDNF) is a patented innovation of Dr. Rajendra Prasad Central Agricultural University, Pusa, designed to combat child malnutrition through a simple, nutritious, and affordable ready-to-eat product.

a) Key Features:

- **Composition:** Made from wheat, green gram, ghee, milk powder, and sugar – ingredients that are locally available and culturally acceptable.
- **Nutritional Value:**
  - Provides 500 kcal energy per 100 g.
  - Supplies 15 g of protein, making it rich in both calories and high-quality protein.
  - Balanced macronutrient composition supports healthy growth and development.
- **Target Group:** Especially formulated for young children suffering from undernutrition.

b) Advantages:

- **Convenient & Ready-to-Eat** – requires no cooking, suitable for households with limited resources.
- **Effective in Reducing Malnutrition** – energy- and protein-dense profile directly supports weight gain and recovery.
- **Scalable for Public Health Programs** – can be distributed through ICDS, hospitals, and community nutrition initiatives.
- **Patent Protection:** *Patent No. 448601, granted on 31.08.2023.*

c) **Impact:** By integrating EDNF into child-feeding programs, RPCAU provides a scientifically validated, sustainable, and affordable solution to address Severe Acute Malnutrition (SAM) and reduce the burden of undernutrition in India.

19. Local Market and Household

For any nutrition-focused innovation to succeed, it must move beyond laboratories and pilot studies into the hands of communities. RPCAU ensures that newly developed products—such as fortified foods and farmer-friendly processing tools—are not only accessible at the household level, but also positioned for adoption in local markets.

This dual pathway serves two purposes:

- **Households** benefit from affordable, energy-dense, and protein-rich foods that directly improve family nutrition.
- **Local Markets** empower small entrepreneurs, women's groups, and farmer-producer organizations (FPOs) to sell these products, generating livelihoods while ensuring nutrition reaches the masses.

20. Pathway for Scaling and Outreach

Sustainable nutrition solutions must be designed with scalability in mind. At RPCAU, each product undergoes a journey from research to licensing, and from small-scale demonstration to wider dissemination. Once licensed, products are packaged, branded, and distributed through:

- Self-Help Groups (SHGs) and JEEViKA clusters,
- Hospitals and ICDS centers, and
- Regional markets and community outlets.

This ensures that the benefits of science are not limited to academic discussions, but reach the very people for whom they are intended—children, mothers, and rural families battling malnutrition. One such nutri-dense product is Saheli Dalia, which reflects RPCAU's vision of creating nutritious, affordable, and locally sustainable food solutions. It is a ready-to-cook cereal blend, designed especially for women and children, addressing both dietary needs and livelihood opportunities.

- **Nutritional Value:** Rich in energy, protein, and fiber, Saheli Dalia strengthens immunity and supports maternal and child health.

- **Simple & Culturally Acceptable:** Prepared from locally available grains and pulses, ensuring taste familiarity and high acceptance in households.
- **Women Empowerment:** The product is named *"Saheli" (meaning friend)*, symbolizing support for women's nutrition and livelihoods. It is produced and marketed by Self-Help Groups (SHGs) and JEEViKA women entrepreneurs, providing them with income opportunities.
- **Household Integration:** Families are adopting these foods in their daily diets, leading to better nutrition awareness at the community level.
- **Scaling Up:** With proper packaging and licensing, these foods can be extended to hospitals, ICDS centers, and distant markets, expanding their reach and impact.
- **Dual Benefit:** Improves nutrition security while also generating income and employment for rural women.

21. From Produce to Products – The Miracle of Millets

The "farm-to-fork" approach of RPCAU, where agricultural produce is transformed into nutritious, value-added foods. The "Miracle of Millets" represents RPCAU's vision of transforming traditional farming into a pathway for better nutrition and livelihoods. By processing millets into value-added products such as *atta, dalia, sattu, grits, and milk-based mixes*, farmers and women's groups are creating affordable, healthy foods that fit easily into local diets. Millets are not only nutrient-rich but also climate-smart crops, making them sustainable for both health and the environment. This initiative links agriculture with nutrition and entrepreneurship, ensuring that farmers, SHGs, and FPOs benefit economically while communities gain access to wholesome foods. Ultimately, millet-based innovations embody a farm-to-fork approach, strengthening food security, empowering rural households, and promoting health at the grassroots level.

Conclusion

Nutritional security cannot be achieved through food availability alone; it requires deliberate efforts to improve dietary diversity, agricultural innovations, and community-level awareness. The experiences of RPCAU, Pusa, demonstrate how integrating nutrition-sensitive agriculture with social empowerment can bring about real change. Interventions such as nutrition gardens, home-based recipes for malnourished children, biofortified crops, and energy-dense ready-to-

eat foods directly address hidden hunger and micronutrient deficiencies. Equally important are the technological innovations like the *Rajendra Hand Cranked Chakki*, *Electric Okhali*, and *Energy-Dense Nutritive Food*, which reduce drudgery, promote value addition, and create income-generating opportunities for rural women and farmers. Initiatives such as Saheli Dalia and millet-based products showcase the successful blending of local wisdom with scientific research, ensuring foods are culturally acceptable, affordable, and nutritionally rich. By strengthening linkages between agriculture, health, education, ICDS, and rural development, RPCAU has built models that are replicable and scalable. These initiatives not only improve nutritional outcomes but also empower women, enhance livelihoods, and foster community resilience. In essence, the journey from farm to fork—whether through diet diversification, biofortification, or rural food processing innovations—offers a sustainable pathway to end malnutrition. The collective efforts of institutions, government departments, SHGs, and local communities highlight that nutritional security is best achieved when agriculture and nutrition work hand in hand, with people at the center of change.

Insights on 17 Dietary Guidelines for Indians by ICMR-NIN 2024: Holistic Health through Holistic Diet

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Abstract

Nutrition is the foundation of life, significantly influencing every stage of the human journey. It drives growth, supports development, sustains physiological functions, and fortifies the body against disease. Beyond providing energy, nutrition shapes health outcomes, safeguards against deficiencies, and is a robust defence against diet-related non-communicable diseases (DR-NCDs). In India, the nutritional landscape was marked by complex challenges of dual burden, where persistent undernutrition exists alongside a rapidly growing prevalence of lifestyle-related disorders such as cardiovascular disease, diabetes, and hypertension. This paradox is further complicated by poor dietary practices, which are implicated in over half of the nation's health issues. The shift toward high-fat, sugar, and salt (HFSS) processed foods, which are often cheaper, more accessible, and heavily marketed, combined with declining physical activity, has contributed to the rise in childhood obesity and long-term metabolic risks. Traditional, nutrient-rich home-cooked meals are increasingly being displaced, perpetuating cycles of ill health. To constructively address these challenges, this chapter presents the Indian Council of Medical Research–National Institute of Nutrition (ICMR–NIN) 17 dietary guidelines. These comprehensive, evidence-based recommendations were formulated to address India's unique nutritional challenges and to guide individuals toward healthier and more sustainable dietary patterns by integrating nutrition, food safety and culturally appropriate practices.

Keywords*: Guidelines, High-Fat, Sugar and Salt (HFSS), Non-Communicable disease, Nutrition*

Introduction

Nutrition plays a vital role throughout the human lifespan, beginning from the fetus to old age. Adequate and balanced nutrition supports optimal growth, development, and maintenance of health, while preventing the adverse effects of nutritional deficiencies and minimizing the risk of diet related non-communicable diseases (DR-NCDs) later in life. India faces the dual burden of persistent under-nutrition alongside a rising prevalence of lifestyle related chronic diseases such as cardiovascular diseases, diabetes and hypertension. The Indian Council of Medical Research, National Institute of Nutrition (ICMR-NIN) has developed comprehensive Dietary Guidelines (17) for Indians to capture the diverse cultural, culinary, and nutritional contexts of the country. These are based on the scientific evidence in the current day and aim at promoting the health and disease prevention across all age groups, including vulnerable populations like infants, pregnant women, the elderly, and adolescents.

Fig.1.Overview of 17 Dietary Guidelines for Indians (ICMR-NIN, 2024)

CURRENT NUTRITION SCENARIO

In India, the prevalence of severe forms of undernutrition, such as marasmus and kwashiorkor, has declined. However, hidden forms of undernutrition and anemia remain pressing public health concerns. Poor dietary habits contribute to 56.4% of overall health issues. Adopting a healthy diet and engaging in regular physical activity can significantly diminish the risk of developing heart disease and hypertension, as well as potentially prevent up to 80% of cases of type 2 diabetes, thereby averting numerous premature deaths (ICMR, 2024). Changing dietary habits, marked by increased consumption of high-fat, sugar and salt (HFSS) processed foods and reduced physical activity, are causing a rise in childhood obesity and long-term health risks. HFSS foods are often cheaper, more accessible, and heavily advertised, influencing poor dietary choices. This leads to nutrient deficiencies like iron and folic acid deficiency, which contribute to anemia and further increase rates of overweight and obesity.

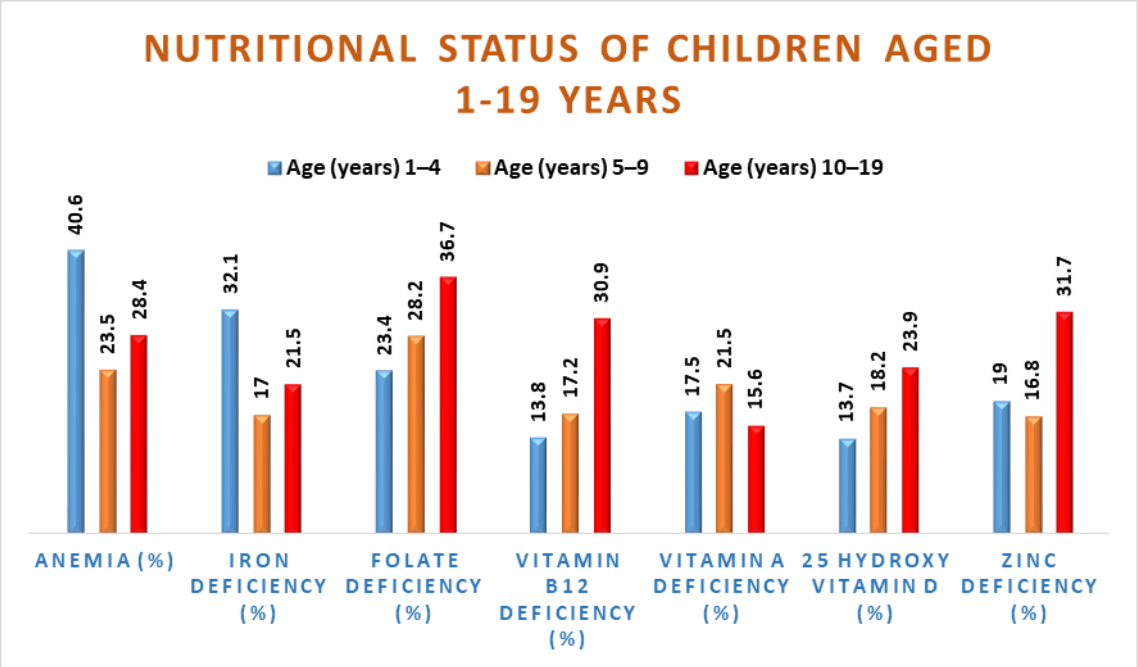

Fig.2.Nutritional Status of Children Aged 1-19 years (CNNS, 2019)

GUIDELINE 1: EAT A DIVERSE RANGE OF FOODS FOR A HEALTHY DIET

A balanced diet supplies essential macronutrients and micronutrients while providing adequate dietary fiber. The World Health Organization (WHO) for daily energy intake recommends that 50–55% of total calories come from carbohydrates (preferably whole grains), 10–15% from proteins, and 20–30% from healthy fats, with added sugars limited to <10% (WHO, 2022). Monteiro *et al.* (2019) found that higher consumption of whole grains, legumes, and nuts significantly reduces mortality risks, whereas ultra-processed foods (UPFs) increase the

likelihood of obesity and cardiovascular diseases. For vegetarians, key nutrients like vitamin B12 (found in fortified foods and dairy) and omega-3 fatty acids (from flaxseeds, chia seeds, and walnuts) require special attention to prevent deficiencies (Craig and Mangels, 2009). Structured meal timing, such as eating 2–3 balanced meals daily without excessive snacking, may also improve metabolic health (Paoli *et al.,* 2019).

Foods are categorized into 10 groups to guide individuals in making balanced dietary choices. To maintain good health, aim to include a variety of foods from at least 5 to 7 of these groups every day. Additionally, incorporating other food options 2 to 3 times a week can enhance your overall nutrition.

Nutrient requirements represent the quantities of essential nutrients needed to maintain optimal health and physiological function. These requirements are based on the following key metrics:

- **Estimated Average Requirement (EAR):** The median daily intake sufficient for 50% of a population
- **Recommended Dietary Allowance (RDA):** Set at the 97.5th percentile (EAR + 2 standard deviations) to cover nearly all healthy individuals.
- **Tolerable Upper Limit (TUL):** Defines the maximum safe intake to prevent toxicity.

While dietary planning for populations is based on EAR, RDA serves as a benchmark for clinical supplementation in deficient individuals. A critical consideration in applying these values is bioavailability, the proportion of ingested nutrients that is absorbed and utilized, which varies based on dietary composition and individual factors. These requirements are tailored for different physiological groups, including infants, children, adolescents, pregnant and lactating women, and adults, accounting for variations in physical activity and metabolic demands. Although daily intake may fluctuate, meeting these nutritional benchmarks over time ensures sustained health and prevents deficiency-related disorders.

GUIDELINE 2: ENSURE EXTRA NUTRITION AND HEALTHCARE FOR PREGNANT AND LACTATING WOMEN

Pregnancy and lactation are physiologically demanding periods requiring substantial nutritional support to ensure maternal health and optimal fetal development. A well-nourished mother at conception provides essential vitamins (A, D, B12, folic acid), minerals (iron, iodine, calcium), fatty acids (LCn-3 PUFAs), and amino acids critical for fetal organogenesis, immune function, and brain development. Conversely, maternal undernutrition increases risks of small

for gestational age (SGA) or low birth weight (LBW) infants, predisposing offspring to childhood infections, stunting, and adult-onset metabolic disorders like diabetes and hypertension. The first 1,000 days (conception to age two) are particularly pivotal, with maternal diet directly influencing long-term health trajectories. Pre-pregnancy nutrition assessed through BMI, heamoglobin, and metabolic markers are foundational. Recommended gestational weight gain varies by BMI: 10–12 kg (normal BMI: 18.5–23), 5–9 kg (overweight/obese), and higher for underweight women. Key nutrients like iron (60 mg supplements post-12 weeks), folic acid (0.5 mg in first trimester), and calcium (1,000 mg/day) must be prioritized, with attention to bioavailability—iron absorption improves with vitamin C, while plant-based diets may require fortified foods or supplements for B12 and LCn-3 PUFAs.

Lifestyle and Postpartum Considerations

Beyond diet, hydration (>2 L/day), restricted caffeine, and food safety are critical to mitigate risks. Antenatal care (≥4 checkups), moderate exercise, and avoiding tobacco/alcohol further safeguard pregnancy outcomes. Lactation escalates energy needs an extra 600 kcal/day (first 6 months) and 520 kcal/day (thereafter), alongside continued iron-folic acid supplementation. Protein intake rises by 13.6 g/day initially, tapering to 10.6 g/day. These measures, coupled with 2–3 hours of daytime rest, support milk production and maternal recovery. Together, evidence-based nutritional and lifestyle interventions during this critical window reduce intergenerational cycles of malnutrition and chronic disease.

GUIDELINE 3: BREASTFEEDING EXCLUSIVELY FOR SIX MONTHS AND CONTINUE TILL TWO YEARS AND BEYOND

Breast milk is natural and complete food for infants, essential for their normal growth and healthy development. It provides important nutrients, antibodies, and other beneficial components that support healthy growth. WHO recommends exclusive breastfeeding for the first 6 months. After that, continue breastfeeding along with complementary foods for up to two years or longer. Starting breastfeeding early, within one hour of birth, helps with uterine contractions, reduces postpartum bleeding, and promotes successful lactation.

Colostrum, the first milk produced is rich in immunoglobulins (IgA), vitamin A, and anti-infective factors, offering critical immune protection to new borns. Horta and Victora (2013) confirm that breastfed infants have a 14% lower risk of childhood overweight/obesity and a 35% reduced likelihood of type 2 diabetes later in life compared to formula-fed infants.

Additionally, breastfeeding enhances cognitive development and reduces infant mortality from infections such as diarrhea and pneumonia due to its antimicrobial properties (pH 6.36–7.36) and gut microbiome-supporting prebiotics.

For mothers, breastfeeding lowers the risk of breast cancer (4.3% reduction per 12 months of breastfeeding) and ovarian cancer (28% lower risk) (Collaborative Group on Hormonal Factors in Breast Cancer, 2002). Conversely, non-breastfed infants face higher risks of infections, leukemia, and sudden infant death syndrome (SIDS), while mothers may experience increased susceptibility to metabolic and cardiovascular diseases. Practical strategies like frequent suckling, proper latching, and hygienic milk expression enable working mothers to sustain breastfeeding. The breastfed infants show better Emotional Quotient compared to non-breastfed infants (ICMR-NIN, 2024). Given its unparalleled benefits, "breast milk is the best milk" is a vital public health intervention for ensuring long-term health outcomes.

GUIDELINE 4: HOMEMADE SEMISOLIDS TO INFANTS AFTER SIX MONTHS

At six months of age, breast milk alone becomes insufficient to meet infants' nutritional demands, providing only 500 kcal and 5g protein daily against requirements of 650-720 kcal and 9-10.5g protein. This critical period necessitates the feeding of semi-solid complementary foods to bridge the nutritional gap. Micronutrient needs are particularly high, being 5-10 times greater than adult requirements per kilogram body weight, demanding nutrient-dense foods with high-quality protein.

The Minimum Dietary Diversity (MDD) framework recommends daily inclusion of five food groups:

- Cereals, millets,
- Pulses, egg, meat,
- Nuts and Oilseeds,
- breast milk or milk and milk products,
- Green Leaf Vegetables and fruits.

Meal frequency should progress daily from twice (6-8 months) to thrice (9-24 months), with non-breastfed infants requiring four meals plus milk feeds. Home-prepared foods are preferred for superior nutrient bioavailability and digestibility, while processed HFSS foods should be avoided. Infant feeding requires special consideration of developmental readiness. Initial food rejection reflects immature oromotor coordination rather than dislike. Semi-solid textures (e.g.,

mashed pulses instead of watery preparations) promote swallowing skill development through regular exposure. Responsive feeding practices involving reciprocal caregiver, infant interaction and recognition of hunger/satiety cues will enhance dietary acceptance and support neurodevelopment.

For managing lactose intolerance during diarrhea, fermented dairy or cereal-milk combinations maintain nutrient intake while reducing osmotic load. Traditional food processing techniques like germination produce Amylase-Rich Foods (ARFs) that enzymatically reduce food bulk and improve energy density of weaning gruels. These strategies collectively address the critical nutritional shift from breastfeeding to family foods while supporting optimal growth and development.

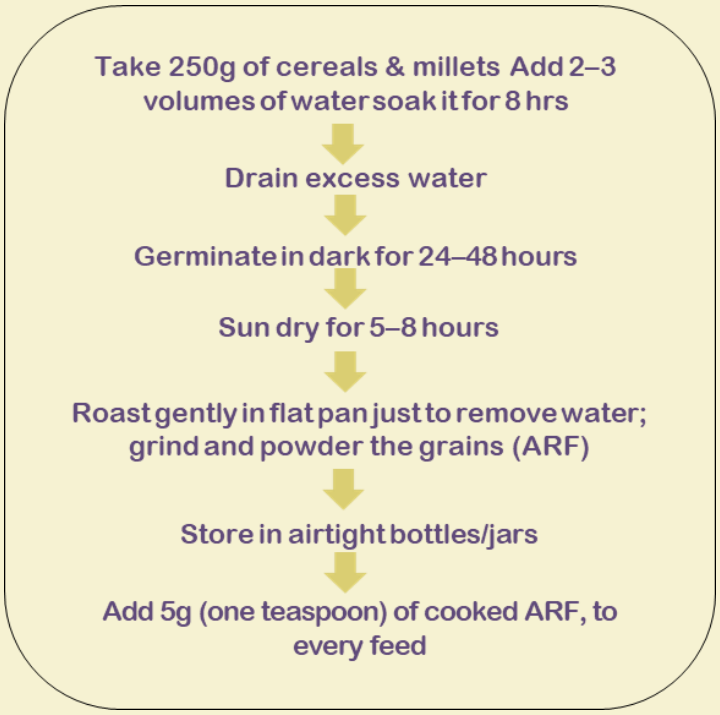

Fig.3. Flow Chart for Preparation of Amylase Rich Foods

GUIDELINE 5: ENSURE PROPER DIETS FOR CHILDREN AND ADOLESCENTS

Children experience rapid growth, with birth weight doubling by 5 months and tripling by 1 year, while adolescence (10-19 years) brings accelerated physical development requiring increased nutrients. Key requirements include calcium (600-1300mg/day from dairy, ragi, sesame) for bone mass accumulation, iron (10-15mg/day from greens, pulses, meat with Vitamin C enhancers), and high-quality protein (1.2-1.5g/kg/day from diverse sources). Dietary recommendations emphasize: energy-dense foods for young children; whole grains, pulses and nuts for fiber; restricted HFSS foods; and meal timing to avoid iron inhibitors like tea. Critical

lifestyle factors include daily physical activity (≥60 minutes), sunlight exposure for Vitamin D synthesis, and complete avoidance of tobacco/alcohol. During illness, maintain feeding with energy-rich semi-solids (khichdi, mashed fruits), use ORS for diarrhea, and implement catch-up feeding (150% RDA) post-recovery to break the malnutrition-infection cycle. These measures support optimal growth velocity, bone mineralization, and long-term health outcomes.

GUIDELINE 6: CONSUME DIET RICH IN VEGETABLES AND LEGUMES

In India, vegetables and fruits consumption is markedly insufficient. Current intake levels average between 100g and 200g per day, which is significantly lower than the recommended daily intake of 500g. A diet rich in fresh vegetables and fruits reduces the risk of chronic non-communicable diseases like diabetes, heart disease, and cancer. These foods serve as essential sources of micronutrients, including vitamins and minerals, as well as phytonutrients, bioactive compounds, and dietary fiber, all of which are crucial for maintaining overall health. Most vegetables are low in calories, with fewer than 20 calories per 100g when raw, while most fruits contain less than 60 calories per 100g. In contrast, potatoes and sweet potatoes (70–100 calories per 100g), along with energy-dense fruits like bananas, provide significant carbohydrate content.

Leafy greens are particularly nutrient-dense, supplying carotenoids (precursors to vitamin A), iron, folate, calcium, and other essential micronutrients. Additionally, the prebiotic fibers in many vegetables and fruits promote a healthy gut microbiota, enhancing microbial diversity and metabolic function. Vegetables are valuable source of vitamins (such as A, C, E, B) and minerals. Also provides essential minerals like Fe, Cu, Zn, Ca, Mg, and K. They contain phytochemical compounds, including carotenoids, alkaloids, terpenoids, flavonoids, phenolics, and bioactive peptides. Furthermore, vegetables are abundant in antioxidants, high in dietary fiber, and low in fat and calories, all of which contribute to preventing overweight and promoting overall health.

Microgreens: Microgreens are young, tender plants, harvested within a week to ten days of sowing, typically having one to two sets of leaves. These emerging functional foods are rich in nutrients like amino acids, fatty acids, micronutrients, and bioactive compounds, offering potential to prevent deficiencies and diseases even in small quantities. Specific examples include red cabbage microgreens, which can favorably modulate lipid profiles, and fenugreek microgreens, which show anti-diabetic activity. They can be used to embellish various recipes,

including salads, soups, and sandwiches. MANAGE (2021) demonstrated that selected microgreen varieties like amaranth and fenugreek contain up to 40% higher polyphenol concentrations compared to mature plants, with significant antioxidant and anti-diabetic potential.

GUIDELINE 7: MODERATE USE OF OILS/FATS

Fats(lipids), are mainly of three types: 1) saturated fatty acids (SFA), 2) monounsaturated fatty acids (MUFA), and 3) polyunsaturated fatty acids (PUFA). While the body can synthesize SFAs and MUFAs, two PUFAs: linoleic acid (omega-6/n-6) and alpha-linolenic acid (omega-3/n-3) are essential fatty acids (EFAs) that must be obtained from dietary sources like vegetable oils, nuts, seeds, and fatty fish. SFAs, found in coconut oil, ghee, butter, and animal fats, should be consumed in moderation as excessive intake increases LDL cholesterol and cardiovascular disease risk. Trans fats (TFA), present in hydrogenated oils (vanaspati), margarine, and processed foods, are particularly harmful as they raise LDL while lowering HDL cholesterol and should be strictly avoided.

Fats serve multiple physiological roles, including energy provision (9 kcal/g), absorption of fat-soluble vitamins (A, D, E, K), cell membrane structure (PUFA/MUFA), hormone synthesis (cholesterol), and brain and nerve development (DHA, ALA). They also provide satiety, enhance food palatability, and protect vital organs. Dietary fats can be classified as visible fats (oils, butter, ghee) or invisible fats (naturally present in cereals, pulses, nuts, seeds, and animal products). While visible fats are intentionally added during cooking, invisible fats contribute significantly to total fat intake and provide essential fatty acids.

For optimal health, prioritize MUFA/PUFA rich oils (mustard, olive, soyabean) and limit SFA intake. Avoid trans-fat completely due to their association with heart disease, stroke, and metabolic disorders. When selecting oils, prefer unrefined or cold-pressed varieties, which retain beneficial antioxidants and phytochemicals generally lost during refining. Avoid reheating oils, as this promotes oxidation and the formation of harmful compounds. Instead, filter and repurpose used oil for curries rather than repeated frying. Including nuts, seeds, and fatty fish in the diet ensures adequate intake of EFAs and supports overall health.

GUDELINE 8: OBTAIN PROTEINS AND ESSENTIAL AMINO ACIDS (EAA) FROM PROPER COMBINATION OF FOODS AVOIDING PROTEIN SUPPLEMENTS TO BUILD MUSCLE MASS

Proteins serve as fundamental building blocks for all cells and tissues, critical for enzyme and hormone production, structural support (cell membranes), and transport functions (hemoglobin). While the body utilizes 20 amino acids (AAs), 9 are essential (EAAs) and must be obtained through diet. Indian diets often meet protein quantity needs but face quality challenges due to variable EAA profiles. Vegetarian diets can achieve EAA adequacy through strategic combinations like cereals (methionine-rich) with pulses (lysine-rich) in a 3:1 ratio, supplemented by milk (250ml/day) for enhanced quality. Non-vegetarian sources (eggs, meat, fish) naturally provide complete proteins. Protein digestibility ranges from 70%–85% in plant sources, with diverse vegan diets yielding 60g of utilizable protein daily, meeting adult requirements. While protein supplements (wheat, soy, pea) are popular, they are unnecessary for most and may contain additives; excess protein is metabolized for energy or excreted, potentially straining kidneys and leaching calcium. Crucially, resistance exercise is vital to direct protein toward muscle synthesis, and adequate carbohydrate/fat intake prevents protein catabolism for energy. A balanced, varied diet prioritizing whole foods over supplements optimizes protein utilization for growth, repair, and metabolic health.

Table 1: Plant Foods and the Limiting Amino Acids (ICMR,2024)

Grains (cereals, millets)	Lysine, Threonine, Tryptophan
Pulses	Methionine
Nuts/seeds	Lysine

GUIDELINE 9: MAINTAIN A HEALTHY LIFE STYLE TO PREVENT OBESITY

The rising prevalence of obesity in both rural and urban populations across India is a significant public health concern. Presently, nearly 25% of Indians are obese, with a marked increase in abdominal adiposity. This form of fat accumulation, especially around internal organs, is a key risk factor for type 2 diabetes, fatty liver disease, hypertension, gallstones, certain cancers, osteoarthritis, and several psycho-social problems (ICMR,2024). Central obesity is characterised by increased waist circumference, indicating the accumulation of visceral fat within the abdominal cavity. This is more harmful than general obesity and is now a well-

established risk factor for multiple chronic lifestyle diseases. The waist circumference cut-off to identify abdominal obesity is >90 cm for men and >80 cm for women. In India, it is concerning that adults in urban over 53% and in rural 19% are classified as having abdominal obesity.

The Body Mass Index (BMI) serves as a simple measure of weight relative to height, helping to categorize individuals into underweight, normal weight, overweight, and obesity.

$$\mathbf{BMI}=\frac{\mathbf{Weight\ (kg)}}{\mathbf{Height}\ (\boldsymbol{m})^{\mathbf{2}}}$$

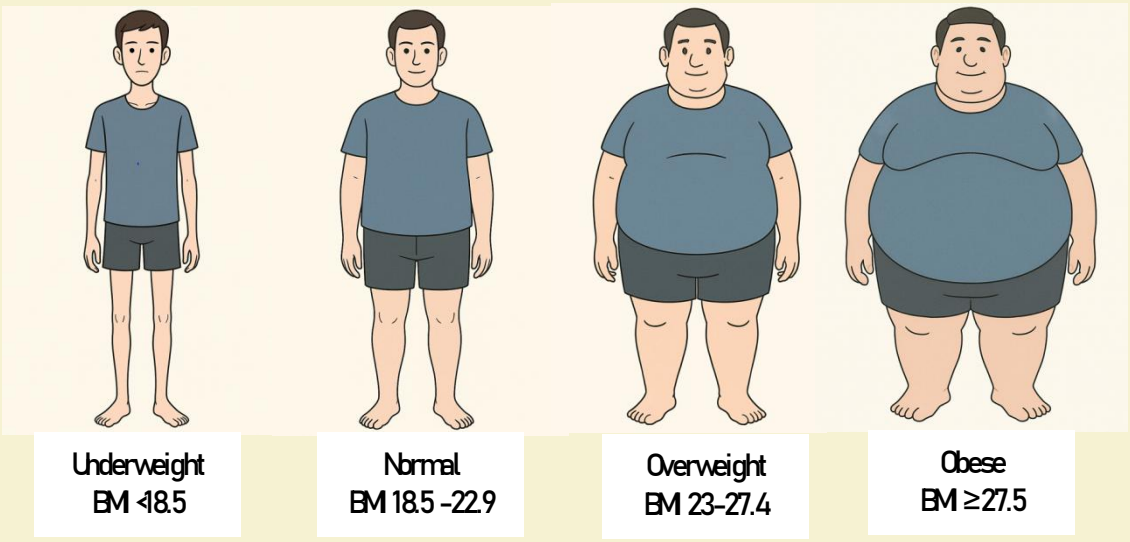

Fig.4. BMI Classification for Asian Indians (ICMR-NIN, 2024)

Glycemic Index and Glycemic Load: Foods high in sugar or refined carbohydrates have a high glycemic index (GI) and glycemic load (GL). This means they're digested quickly, causing rapid spikes in blood sugar and insulin. This can lead to fat accumulation, especially in inactive people. The Glycemic Index (GI) is a ranking system from 0 to 100 that measures how fast a food raises blood sugar. Glucose has a GI of 100.

- **High GI foods (≥ 70):** Digested quickly, causing a sharp rise in blood sugar.
- **Low GI foods (≤ 55):** Digested slowly, resulting in a gradual and beneficial rise in blood sugar and insulin for stable energy.

Choosing low GI foods like whole grains, legumes, and non-starchy vegetables helps control appetite, prevent insulin resistance, and manage weight. The obesity epidemic in India is caused by a mix of factors including high-calorie diets, sedentary lifestyles, processed foods, genetics,

and poor sleep. Combating this requires a balanced diet, regular exercise, good sleep, and consistent weight monitoring through gradual, sustainable lifestyle changes.

GUIDELINE 10: STAY PHYSICALLY ACTIVE AND EXERCISE REGULARLY FOR SOUND HEALTH

Regular physical activity is essential to maintain a healthy body and mind. It improves **cardiovascular health, muscle strength, joint flexibility, bone density**, and metabolic functions. In today's sedentary lifestyle marked by desk jobs, long commutes, and screen time, physical inactivity has become a major cause of rising obesity and related health problems. People across age groups are now spending more time sitting or reclining, leading to reduced calorie expenditure and impaired metabolism. Biswas et al. (2015) found that prolonged sitting time (>8 hours/day) was associated with a 24% higher risk of cardiovascular mortality, 18% higher cancer mortality, and 91% increased type 2 diabetes risk - independent of exercise habits. WHO (2022) highlighted that physical inactivity causes 5 million premature deaths annually worldwide, with sedentary jobs contributing to 30-50% higher risks of obesity, hypertension and metabolic syndrome.

Physical activity can be structured or incidental. Structured activity is planned and repetitive, including exercises like brisk walking, gym workouts, swimming, jogging, cycling, stretching, and strength training. **Yoga** is a structured, holistic activity that combines physical movement with breathing (pranayama) and mental relaxation. **Incidental activity** involves unplanned, routine movements such as household chores, climbing stairs, gardening, walking for errands, workplace movement, and recreational games.

Physical Activities and Their Health Benefits

A well-rounded fitness routine should incorporate four key types of exercise: aerobic, strength training, balance exercises, and flexibility work. Aerobic activities, such as jogging, cycling, and swimming, improve heart and lung function by increasing endurance. Strength training, including weightlifting and resistance exercises, enhances muscle mass and bone density, which is particularly important as we age. Balance exercises such as yoga, tai chi, or backward walking help prevent falls and improve coordination, especially in older adults. Meanwhile, flexibility-focused movements, including stretching and yoga, promote joint mobility, relaxation, and stress relief.

Table 2: Recommended Physical Activity

Age Group	Recommended Duration	Activity Type
Children (5–19 years)	≥ 60 minutes/day	Moderate to vigorous activities; strength exercises at least 3 days/week
Adults (19–60 years)	30–60 minutes/day, ≥5 days/week	Aerobic activities; muscle-strengthening exercises twice a week
Elderly (>60 years)	Similar to adults	Include activities to enhance balance, flexibility, and joint mobility

Incorporating movement into daily life is key to sustaining long-term health. Simple strategies include taking short walking breaks every 30–60 minutes, using stairs instead of elevators, and opting for active transportation like walking or cycling. Encouraging children to play outdoors and participate in sports fosters healthy habits early on. For older adults, gentle activities like yoga, tai chi, or regular walks can enhance stability and mental well-being. Even a daily 30–45-minute brisk walk can significantly improve health outcomes for adults, while children benefit from an hour of active play to prevent obesity. By making physical activity a consistent priority, individuals of all ages can enjoy a healthier, more vibrant life.

GUIDELINE 11: REDUCE SALT INTAKE

Salt, while essential in small amounts, becomes a significant dietary risk when consumed in excess. Sodium, its key component, is vital for fluid balance, nerve transmission, and muscle function, but high intake increases the risk of hypertension, heart disease, stroke, kidney failure, and gastric cancer. ICMR (2024) shows that average salt consumption in India ranges from 3–10 g/day, with 45% of the population exceeding the recommended 5 g/day (2g sodium). Salt preference is learned behaviour, making early reduction beneficial. Requirements may rise with heavy sweating from heat or intense activity. Table salt (sodium chloride) is 40% sodium and 60% chloride. Sodium and potassium together regulate water, electrolytes, and cell functions. WHO advises limiting sodium to 2300 mg/day (5g salt) and consuming 3800 mg potassium daily can be achievable with 400 g vegetables, 100 g fruits, plus nuts and animal-based foods improving the Na: K for better health. All salt types, table, rock, or sea are primarily sodium

chloride, with health impacts driven by quantity rather than variety. Refined salt (99% pure) contains anti-caking agents, while unrefined salt (96% pure) may retain trace minerals. Regional varieties like pink salt (*sendha namak*) and black salt (*kala namak*) differ in taste and composition but offer no real nutritional advantage over moderate use of regular salt. Regardless of type, excessive intake increases hypertension and related health risks.

GUIDELINE 12: CONSUME SAFE AND CLEAN FOODS

Consuming safe and hygienic food is essential for good health, as contaminated or adulterated food can cause food-borne illnesses, damage the intestinal lining, and contribute to undernutrition especially in vulnerable groups like children and pregnant women.

Food safety hazards can arise from:

- **Microbial contamination** (bacteria, viruses, fungi, protozoa) due to poor hygiene, unsafe water, or improper cooking.
- **Chemical contamination** from pesticide residues, cleaning agents, or endemic fluoride.
- **Heavy metal contamination** via polluted soil or water.
- **Natural spoilage** accelerated by moisture, temperature, and poor storage conditions.
- Other risks such as insect/rodent infestation, natural toxins, and use of non-food grade packaging or storing food near chemicals.

Adulteration, whether intentional or accidental, can compromise the substance and quality of food at any stage production, processing, transport, or storage and may render it unsafe depending on the contaminant and its concentration.

Ensuring food safety begins with buying fresh, unspoiled products from trusted sources, free from infestation, foreign matter, or artificial colors. Recognizing quality marks like **AGMARK** (agricultural products) and **ISI** (packaged drinking water, standardized goods) helps identify safe products.

Proper storage prevents spoilage and infestation: Sun-dry grains and store in airtight containers and use regular cleaning and traditional pest deterrents like neem leaves. Food-borne illnesses often result from mishandling perishables, undercooking, poor temperature control, or repeated reheating, which fosters bacterial growth and toxin formation. Safe handling includes:

- Refrigerating below **5°C** to slow microbial growth.
- Keeping cooked food hot above **60°C** if not eaten immediately.
- Cooling food quickly before refrigeration.
- Thorough reheating without repeated cycles.
- Storing raw and cooked foods separately.
- Washing produce before refrigeration.
- Maintaining clean storage environments.

Personal hygiene is critical, wash hands thoroughly, keep nails clean, avoid preparing food with wounds, use clean utensils, and keep animals away from food areas to reduce contamination. To minimize pesticide residues, wash and peel fruits and vegetables, discard outer leaves of greens, choose seasonal/local produce, avoid chemically contaminated water for washing, and cover food during spraying. Cookware safety requires avoiding prolonged storage of acidic or fermented foods in aluminum, untinned brass, copper, or iron vessels to prevent harmful metal leaching. For **Teflon-coated non-stick cookware**, avoid heating above **170°C**, especially when empty, as this can release toxic fumes.

GUIDELINE 13: ADOPT PROPER COOKING METHODS

Cooking methods significantly influence nutrient retention and food safety. Proper pre-cooking practices include thoroughly washing whole fruits and vegetables to remove contaminants while avoiding excessive washing after chopping to prevent loss of water-soluble vitamins. Cereals, pulses, and greens should be washed multiple times for cleanliness. Soaking pulses and cereals reduces cooking time and anti-nutritional factors, enhancing protein digestibility and mineral absorption. Sprouting improves protein quality and vitamin C content, but must be done hygienically to prevent contamination. Between blanching and steaming, steaming is superior for nutrient preservation, as it avoids water immersion that causes loss of water-soluble vitamins, while still maintaining texture and color through gentle cooking and rapid cooling.

Table 3: Methods of cooking and their nutrient retention

Method	Nutrient Retention	Description
Steaming	High	Best for vegetables; retains water-soluble nutrients
Pressure cooking	High	Fast and efficient; preserves proteins and minerals

Boiling (with minimum water)	Moderate	Use leftover water for gravies to retain nutrients
Sauteing	Moderate	Requires minimal oil; suitable for vegetables
Baking/Roasting	Good	Retains nutrients and adds flavor without excess oil
Fermentation	Enhances bioavailability	Improves gut health and increases B-vitamin levels

Avoid Harmful Cooking Methods

- **Deep frying**: Increases fat content and may lead to **acrylamide formation**, a potential carcinogen.
- **Reusing oil**: Promotes oxidative changes and production of **toxic aldehydes**.
- **Overheating oils**: Especially oils high in polyunsaturated fats (PUFAs), which degrade at high temperatures.
- **Charring and burning food**: Leads to the formation of **PAHs (polycyclic aromatic hydrocarbons),** linked to cancer risk.

GUIDELINE 14: DRINK ADEQUATE AMOUNT OF WATER

Water makes up about 70% of the human body and is essential for vital functions like fluid balance, temperature regulation, and waste elimination. Since the body cannot store water, regular intake through food and fluids is crucial; even mild dehydration impairs brain and body functions. Safe drinking water must be free of pathogens (bacteria, viruses, parasites) and harmful chemicals such as pesticides, heavy metals, nitrates, and excess fluoride—the latter beneficial only in low concentrations (1–1.5 mg/L) but harmful if excessive. Boiling water for 10–15 minutes effectively kills microbes but does not remove chemical contaminants. Additional treatments include chlorination, UV, RO, and activated carbon filtration, which help remove chemical impurities. Pre-filtration with a clean cloth aid in removing physical particles.

Beverage guidelines:

- Tender coconut water hydrates naturally but should be avoided by those at risk of high potassium (e.g., kidney or heart patients).
- Avoid synthetic soft drinks as they do not replace water or natural juices.
- Fresh fruit juices can be consumed occasionally in moderation.

- Limit tea and coffee to ≤300 mg caffeine per day; avoid intake around meal times to prevent interference with nutrient absorption.
- Excessive alcohol consumption harms multiple organs, raises cancer risks, and contributes to obesity and cardiovascular issues; moderation or abstinence is advised.

GUIDELINE 15: LIMIT COMSUMPTION OF FOODS HIGH IN FAT, SUGAR, SALT (HFSS) AND ULTRA-PROCESSED FOODS (UPFS)

High Fat, Sugar, and Salt (HFSS) foods are those deriving over 15% of their energy from visible or added fats like cooking oils, ghee, or butter. Most foods undergo some processing to make them safe and palatable. Based on processing level, they can be classified as:

- **Primary processing:** basic cleaning, grading, and packaging (e.g., fruits, vegetables).
- **Secondary processing**: modifying the raw product before final preparation (e.g., milling paddy to rice).
- **Tertiary processing**: Ready-to-eat or near-ready foods (e.g., bakery products, instant meals).
- **Minimally processed foods**: Slight alterations for preservation without major nutrient loss.
- **Ultra-processed foods (UPFs)**: Heavily industrially processed products with multiple additives (preservatives, sweeteners, colorings, flavorings, emulsifiers) uncommon in traditional cooking.

High intake of HFSS foods and UPFs often energy-dense, nutrient-poor, highly palatable, and aggressively marketed has been linked to obesity, type 2 diabetes, heart disease, and micronutrient deficiencies, particularly among children and adolescents. These products tend to replace traditional, home-cooked, nutrient-rich meals.

GUIDELINE 16: ENSURE NUTRIENT-RICH FOODS IN THE DIETS OF ELDERLY

Ageing brings physiological changes that affect dietary intake, digestion, and nutrient absorption. Reduced appetite, poor dental health, slower metabolism, and limited mobility are common in older adults, increasing the risk of malnutrition, muscle loss, weak bones**,** and chronic conditions like diabetes and hypertension**.** A balanced diet for the elderly should focus on **easy-to-digest, nutrient-dense, and soft-textured foods**. Protein is essential to prevent

muscle loss and maintain immunity. Good sources include **milk, curd, soft-cooked pulses, eggs, and fish**. Adequate intake of **calcium and vitamin D** is important for bone strength, which can be met through **milk, ragi, sesame seeds,** and **safe sun exposure.** Deficiencies of **vitamin B12, folate,** and **iron** are also common in older adults, particularly in those with low intake of animal foods. **Fiber and fluids** must be included to prevent constipation and support digestion. Encourage **seasonal fruits, vegetables, whole grains,** and **adequate water intake** throughout the day. Soft preparations like **porridge, idli, khichdi, dal, stewed fruits, soups**, and mashed vegetables are ideal. Spices and herbs can help improve taste and appetite. Eating in small, frequent meals, with family support and a pleasant environment, encourages regular intake. Gentle physical activity like walking or yoga also supports digestion, mood, and mobility

GUIDELINE 17: READ FOOD LABELS FOR INFORMED HEALTHY CHOICES

Food labels are important to help consumers make informed, healthy, and safe food choices. All packaged foods must carry a label that provides key information on the product's composition, safety, and nutritional value.

A typical label includes:

- Product name
- List of ingredients (in descending order by weight, with the first being the most abundant)
- Net weight
- Manufacturer details
- Batch number
- Date of manufacture and expiry/use-by date
- Allergen warnings
- Storage instructions and shelf life

For imported foods, the **country of origin** and importer's details must also be mentioned. Products listing **sugar, refined flour, or hydrogenated oil** among the first few ingredients are generally less healthy. Always check manufacturing and expiry dates to ensure freshness and safety, as consuming expired products increases the risk of foodborne illness. Follow storage instructions and any usage directions to maintain product quality.

Common symbols and marks on labels:

- **FSSAI logo & license number**: Confirms that the manufacturer is licensed and complies with food safety standards.
- **Green dot inside green square**: Vegetarian.
- **Brown triangle inside brown square**: Non-vegetarian (contains at least one ingredient of animal origin, including eggs but excluding milk).
- **Fortified food logo**: Indicates that essential vitamins and minerals have been added to bridge nutrient gaps (e.g., fortified wheat flour, rice, milk, oil, salt).
- **Vegan logo**: For products free from animal-derived ingredients, additives, or processing aids (including milk and honey).
- **ISI mark**: Mandatory on packaged drinking/mineral water and some processed foods like infant food and milk, though it may be phased out as FSSAI becomes the sole certifying authority.
- **AGMARK**: Found on agricultural products like vegetable oil, pulses, cereals, spices, honey, fruits, and vegetables, certifying quality.

The nutrient content declaration, usually on the back of the package, lists nutrient values per 100 g, 100 ml, or serving size, along with the percentage of the **Recommended Dietary Allowance (RDA)** per serving. While FSSAI regulates nutrition and health claims, consumers should always cross-check these claims against the ingredient list and nutrition facts before making a purchase.

Fig.5.Common Food Labels and Certifications in India

Conclusion

The ICMR–NIN Dietary Guidelines provide a comprehensive, evidence-based framework to improve nutritional well-being serving as a practical blueprint for advancing public health in India. The implementation of these guidelines has the potential to promote health and well-being throughout India's diverse population while fostering sustainable and safe food systems that serve the broader community effectively.

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Climate-Resilient Agroecological Models for Food and Nutritional Security in India: Strategies, Interventions, and Outcomes

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Abstract

This chapter examines how agroecological models, integrating biodiversity, ecological processes, and community participation, offer sustainable solutions by enhancing resilience, resource efficiency, and equity. It explores agroecological principles and region-specific models, highlighting successful interventions such as Kerala's KERA project and the Mayyil rice revival. Additionally, it demonstrates how integrated farming, indigenous seeds, women- and tribal-led enterprises, and climate-smart practices can simultaneously boost productivity, restore ecosystems, and empower marginalized groups. Furthermore, it explains about monitoring frameworks like the Climate Resilience Index and Total Factor Productivity. The chapter also underscores the need for policy convergence, climate finance, gender-responsive strategies, and farmer-led innovation to mainstream agroecology. Emphasizing a shift from input-intensive to knowledge-intensive and regenerative practices, it positions agroecology as a cornerstone for resilient, inclusive, and sustainable food systems in India.

1. Introduction

Agriculture, the cornerstone of food and nutritional security, is under increasing threat from climate variability. India, with its diverse agroecological zones and large agrarian population, faces compounded challenges due to rising temperatures, erratic rainfall, pest resurgence, and soil degradation. In this context, agroecological models rooted in resilience, sustainability, and local adaptation are emerging as transformative solutions. Globally, the Intergovernmental

Panel on Climate Change (IPCC) has emphasized that agriculture in tropical and subtropical regions, such as India, will experience substantial yield reductions if adaptation measures are not accelerated (Tchonkouang *et al.,* 2024). India's heavy dependence on monsoon rains, coupled with small and fragmented landholdings, heightens its vulnerability to climate-induced shocks. Additionally, climate change exacerbates underlying socio-economic challenges such as rural poverty, market instability, and nutritional deficiencies. For instance, projections indicate that, climate change could reduce yields of key staples like rice and wheat by a large extend in the absence of adaptive interventions, thereby threatening both household and national food security. Against this backdrop, agroecological models represent a transformative response, bridging ecological science, traditional knowledge, and modern innovation to build resilience within food systems. These models operate on principles such as diversification of crops and livelihoods, soil health regeneration, water use efficiency, integration of silviculture and livestock, and participatory governance. They not only enhance adaptive capacity but also contribute to climate change mitigation through carbon sequestration, reduced reliance on synthetic inputs, and conservation of agrobiodiversity. Furthermore, agroecology aligns with Sustainable Development Goals (SDGs), particularly those related to zero hunger, climate action, and life on land. In the Indian context, adopting agroecological approaches requires region specific strategies that address local agroclimatic conditions, cropping systems, and socio-economic realities. States like Kerala, characterised by high rainfall variability, fragmented farms, and a high dependence on perennial crops, demand tailored models that combine climate resilient crop varieties, integrated farming systems, and landscape level resource management. This chapter explores how agroecological models can help Indian agriculture, particularly in vulnerable regions like Kerala, adapt to climate change while ensuring food and nutritional security. The chapter synthesizes agroecological principles, region-specific interventions, case studies, and policy initiatives such as the KERA project. It concludes by highlighting the potential of agroecological transformation in enhancing resilience, equity, and environmental sustainability.

2. Climate Change and Indian Agriculture

Climate change is no longer a distant concern for the future; it is a present and accelerating reality that is already influencing India's agricultural systems. The agriculture sector, contributing approximately 15% to the country's GDP and providing livelihoods to over half of the population, is among the most climate sensitive sectors of the economy. Given India's dependence on seasonal monsoons, smallholder-dominated farming structure, and diversity of

agroecological zones, even slight climatic deviations can have far-reaching consequences. Recent projections indicate that climate variability could impose a 4–9% annual impact on agricultural productivity, which translates into an estimated 1.5% loss in GDP each year. Such losses are not confined to economic measures, they directly influence food availability, nutritional outcomes, and rural livelihoods, particularly among vulnerable populations. The key climate-related challenges to Indian agriculture include:

1. Crop yield reductions: Staple crops such as rice and wheat are projected to experience a 6–10% decline in yields by 2030 under current climate scenarios, with greater reductions likely in rain-fed regions. Higher night time temperatures can impair grain filling in wheat, while erratic rainfall during critical growth stages of rice can reduce panicle initiation and grain set (Khanal *et al.,* 2024). Yield losses in other crops, including pulses and oilseeds, are also anticipated due to shortened growing seasons and water stress.

2. Heat stress and rainfall variability: Increased frequency of heat waves and shifts in rainfall patterns disrupt traditional sowing and harvesting schedules, forcing farmers to adapt cropping calendars. Heat stress during flowering in crops like maize, pigeon pea, and cotton can reduce pollen viability, lowering yields. In regions like central India, delayed or early monsoons can lead to missed planting windows, while unseasonal rainfall during maturity stages can damage standing crops.

3. Emerging pest patterns and diseases: Rising temperatures and altered humidity regimes create favourable conditions for the spread of pests and pathogens into previously unaffected areas.

4. Soil degradation: Climate extremes are intensifying soil erosion and fertility loss. High intensity rainfall events wash away fertile topsoil, while prolonged droughts reduce soil microbial activity and water holding capacity. Rising temperatures accelerate the decomposition of organic matter, lowering soil carbon stocks critical for long-term productivity. Coastal agriculture faces additional threats from salinity intrusion due to sea-level rise, particularly in low lying regions. Kerala, a unique case with both humid tropics and highlands, has experienced increasing droughts and floods and it caused ₹2,723 crore in damage in flood occurred in 2018. Moreover, 2023 droughts affected over 56,000 farmers. This underscores the urgent need for resilient agroecological frameworks to secure livelihoods and regional food systems.

Together, these challenges form a multi-dimensional risk landscape for Indian agriculture, where climate shocks are not isolated events but compound stressors that interact with socio-economic vulnerabilities. Addressing them requires integrated climate resilient strategies that combine technological innovation, agroecological practices, and robust policy support.

3. Agroecological Principles and Their Relevance

Agroecology integrates ecological science with traditional knowledge and participatory approaches to transform food systems. It emphasizes:

- **Biodiversity:** By promoting polycultures, intercropping, and crop-livestock integration, agroecology enhances ecological services and resource use to support a more robust and sustainable food system. Through simulating natural ecosystems, these methods boost biodiversity on farms, which can lessen dependency on outside inputs, increase soil health, and better control pests and diseases (Diyaolu and Folarin, 2024).
- **Synergy:** Refers to the way that many components of the farming system—such as crops, animals, insects, and soil microbes—cooperate to improve one another's capabilities. For instance, healthy soil increases the availability of nutrients for plants, which in turn encourages beneficial insects that help with pollination and pest management. A more resilient and effective system results from this interconnection (Garibaldi *et al.,* 2018).
- **Recycling:** It encourages on-farm nutrient and energy cycling. Composting, cover crops, and incorporating livestock into the system are among methods that can help achieve this. By reducing waste and optimising the use of resources on-farm, this lessens dependency on external inputs like synthetic fertilisers and pesticides, which can be hazardous to the environment and human health (IPES-Food, 2020).
- **Resilience:** It is the farming system's capacity to tolerate and bounce back from shocks like pest outbreaks, floods, and droughts. This is accomplished by diversifying crops and other system components, which lowers the possibility of total crop failure and gives farmers access to alternate food sources. It builds adaptive capacity through ecosystem diversity and farmer autonomy (Lin, 2011).

Core practices include:

- Use of indigenous seeds adapted to local environments which encourages biodiversity, climatic resilience, and sustainable farming. Due to their natural evolution in certain

areas, these seeds are more resilient to regional pests, diseases, and climate variations, which lessens the need for fertilisers and pesticides. Additionally, this method aids in the preservation of cultural heritage and traditional farming methods (Dwyer *et al.,* 2022).

- Adoption of natural pest control, mulching, and organic fertilization are essential methods for sustainable agriculture that minimise their negative effects on the environment while fostering healthy crops and soil. A more balanced ecology and healthier food result from these techniques decreased dependency on artificial fertilisers and pesticides (Amogha and Bhavana, 2024).
- Home gardens, agroforestry, and climate-smart villages as integrated systems can all be combined to build resilient and sustainable agricultural systems. Through this integration, the advantages of each element are combined to improve lives, increase food security, and advance environmental sustainability (Kumar and Tiwari, 2017).

These principles are not new but echo traditional Indian agricultural wisdom, which is being validated through participatory research and innovation platforms.

4. Regional and Local Agroecological Models in India

India's diverse geography allows for differentiated models of agroecology:

Region	**Focus**
Western Himalayas	Integrated Farming Systems (IFS), terrace farming
Eastern Himalayas	Paddy–fish systems, organic certification
Rajasthan	Agro-Silvo-Pastoral systems, drought-tolerant varieties
Deccan Plateau	Rainfed crop diversification, meteorological services
Coastal Areas	Salinity-resistant crops, fisheries–horticulture integration

Each model leverages local knowledge, resource endowments, and ecosystem characteristics.

5. Operational Agroecological Models

Several scalable models have emerged across India, integrating nutrition, biodiversity, and livelihood diversification into farming systems. This includes:

- Climate-Smart Home Gardens: These are small-scale, nutrient-rich, seasonal gardens, suitable for marginal lands and women-led households. The goal of these gardens is to grow wholesome food that can withstand harsh conditions (Shubha *et al.,* 2022).
- Agroforestry Systems: Integration of fruit trees and vegetable understorey, especially in semi-arid zones.
- Millet-Based Systems: Promote dietary diversity and resilience in tribal areas.
- Integrated Farming Systems (IFS): Combine crops, livestock, aquaculture, and biogas to ensure resource cycling.
- Nutrition-Smart Villages: Community-driven efforts to enhance dietary outcomes and agri-literacy.

These models emphasize low external inputs, community ownership, and resilience to market and climate shocks.

6. Case Study: Kerala's Climate-Resilient Interventions

Kerala has become a front-runner in agroecological transformation through the KERA project (Kerala Climate Resilient Agri-Value Chain Modernization). The project intends to improve the food and agriculture industry in Kerala's resilience and commercialisation, with a focus on smallholder farmers, MSMEs, and FPOs (World Bank Group).

6.1 Key Features of KERA Project

- Funding: World Bank has backed the project by funding $200M
- Coverage: From 14 districts almost 400,000 farmers would get access to the project
- Focus Areas: The project focuses on CSA adoption, value chain modernization, women-led agribusinesses (World Bank Group).

6.2 Major Interventions

- Agroecological farming clusters with organic and diversified crops: This entails grouping farmers into clusters to embrace agroecological practices, with a focus on organic farming techniques and crop diversification in order to promote soil health, biodiversity, and climate change resistance
- Community seed banks and revival of local varieties: Establishing seed banks inside the community to preserve and encourage the use of native and local agricultural varieties, increasing genetic variety, and allowing for local adaptation.

- Water conservation: Rainwater harvesting and micro-irrigation: Employing micro irrigation and rainwater collection strategies to effectively manage water resources, reduces dependency on outside water sources, and encourages water-use efficiency.
- Extension innovations: Agroecology schools, Farmer Field Schools (FFS), and digital advisories: This involves distributing agroecology best practices and knowledge through Farmer Field Schools (FFS), Agroecology Schools, and online advisories, equipping farmers with information and useful skills (KERA, 2023).

7. Success Story: Mayyil Rice Revival

Mayyil Panchayat in Kannur district, Kerala, transformed its fallow paddy lands into a flourishing and extremely productive food system through the "Sampoorna Nellu Krishi," campaign launched in August 2016. This campaign united farmers, agricultural scientists, government agencies, politicians, women, and youth to revitalise paddy cultivation and enhance productivity.

Major achievements include

- Doubling of paddy cultivation area from 300 hectares (in 2016-17) to 600 hectares (in 2017-18).
- An exceptional 4.5-fold increase in paddy productivity, from 2.1 tons per hectare to 6.3 tons per hectare
- Establishment of the Mayyil Rice Producers' Company (MRPC), a farmer-producer organization that procures paddy at fair prices, processes it locally, brands, mills, and markets rice, in June 2017. The company used agroecological practices with zero pesticides
- The empowerment plan has included women-led micro rice mills; at least two mills are operated by women as part of a program for women's empowerment.

This seed-to-market model enhanced income, reversed migration, and revived community farming culture (Kerala State Planning Board, website)

8. Agroecological Extension and Tribal Enterprises

Agroecology thrives on participatory and community-driven extension systems, which empower farmers and indigenous communities while advancing sustainable agriculture. Kerala's efforts include:

8.1 Farmer Field Schools (FFS)

- Contemporary FFS promotes real-time pest management in rice using drones for applying Pseudomonas fluorescens, for precise, efficient, and eco-friendly disease control.
- It also promotes nutrient spraying and the usage of compost enhanced with Trichoderma, to enhance soil health, nutrient availability, plant growth, and resistance to pests and diseases (Dwivedi, 2022)

8.2 Tribal Women Enterprises (EDPs)

- EDP 2: Value addition of forest foods (honey, fruits, tubers) through this initiative tribal women are trained in the processing and value-adding of forest products like fruits, honey, and tubers. By using sustainable harvesting, processing methods, value addition raises the items' economic value and marketability and empowers tribal women to make more money (Alex and Vidyasagaran, 2018)
- EDP 3: Multi-grain nutrimix to combat hidden hunger through the creation and promotion of multi-grain nutrimix products, this effort seeks to fight hidden hunger and improve nutrition in indigenous communities. The program promotes livelihood opportunities and nutritional security by enabling indigenous women to manufacture and sell these nutrimixes (Kerala State Planning Board, 2015).
- EDP 4: Marketing skills for tribal women to run food enterprises through the development of marketing and business skills, this program empowers tribal women to effectively manage and expand their food-based businesses. It offers training on branding, packaging, market access, and sales tactics, in order to link tribal businesses with larger markets, enhance product visibility, and boost profits (Kerala State Women's Development Corporation, website).

9. Climate-Smart Agriculture (CSA): Triple Wins

CSA frameworks enhance:

- Productivity: Even in the face of changing climate circumstances, CSA practices such as the use of drought-resistant crop varieties, better water management, and more effective farming techniques can result in increased yields, guaranteeing food security for a growing population with sustainable input use (Bhatnagar *et al.,* 2024).
- Resilience: Systems buffer against weather events, including droughts, floods, and pest outbreaks by adapting to the changing climate. This covers techniques including

increasing soil health, implementing agroforestry, and crop diversification (Palombi and Sessa, 2013).

- Mitigation: By reducing the use of synthetic fertilisers, encouraging carbon sequestration through agroforestry and cover crops, and possibly utilising renewable energy sources on farms, CSA methods can drastically lower greenhouse gas emissions (Zaman *et al.,* 2021).

Examples include:

- UAV spraying reduces water and chemical use
- Nutrient management enhances both yield and environmental health

CSA complements agroecology by adding climate and market-smart dimensions.

10. Cross-Cutting Issues in Food and Nutritional Security

10.1 Gender Equity

- **Women's roles in seed systems, food processing, and market linkages:** Women play significant role in the selection, preservation, and storage of indigenous types of seeds. They also add value through drying, milling, and packaging, making a substantial contribution to post-harvest processing. They frequently struggle with fair pricing and market access even when they actively participate in marketing (Kurtkoti and Joshi, 2024)
- **Need for gender-responsive training and policy:** In addition to challenging discriminatory practices and assisting female entrepreneurs, gender-responsive policies must guarantee equitable access to resources, targeted information, skill development, and business literacy. Furthermore, women's agency and decision-making must be strengthened (Sandoval, 2011)

10.2 Food Access and Equity

- By encouraging varied, locally-adapted farming methods that lessen dependency on outside inputs and market, agroecology improves affordability and diversity in food baskets (Lavandero *et al.,* 2025).
- Community-led models are essential for guaranteeing equitable access to resources and services, especially for vulnerable groups by emphasising community ownership and participation in decision-making processes. models ensure access for 10.3 Role of Smallholders (Saleheen and Barela, 2025).
- Small farms being the engines of food security, significantly contribute to global production of key crops and supply diverse, nutrient-rich diets to local markets.

- It is evident that integrating them into value chains and offering sufficient support networks is vital for improving their standard of living, raising productivity, and guaranteeing sustainable food production (Kapari *et al.,* 2023).

11. Monitoring, Indicators and Methodologies

Assessing the effectiveness of agroecological models calls for a comprehensive approach that evaluates environmental, economic, and social dimensions. To track agroecological model outcomes:

- Climate Resilience Index (CRI): Measures the capacity of an agricultural system to cope with climate change-induced shocks. It focuses on absorptive, adaptive, and transformative capacity dimensions (Devi *et al.,* 2025).
- Total Factor Productivity (TFP): By comparing the total output to the total inputs used it assesses livelihood gains and economic efficiency (International Food Policy Research Institute, 2020)
- Asset Pentagon framework for evaluating SHGs: Provides a holistic view of the resources and capabilities available to individuals and communities, helping to identify how SHGs contribute to improving these assets (Sarma, 2024).

Implementation involves:

- Participatory assessment: Assessing agroecological models effectively requires active involvement of stakeholders and incorporation of local knowledge and cultural practices. Participatory methods should be used to capture multiple viewpoints, with emphasis on farmer-focused indicators that reflect their unique contexts (Ohly, 2023).
- Context-specific planning for agroecological interventions involves tailoring strategies to the area's social, economic, ecological, and cultural conditions. It should consider local resources, infrastructure, and expertise (Audouin *et al.,* 2019).
- M&E using local and scientific benchmarks for agroecological models blends local insights with scientific data, uses varied assessment tools, and maintains openness with stakeholders. It also emphasizes long-term benefits while remaining flexible, allowing ongoing adjustments based on feedback and evolving conditions (Ohly, 2023).

12. Recommendations and Way Forward

1. Strengthen Knowledge Systems: This requires a multifaceted strategy that fosters farmer-to-farmer learning, harnesses digital technologies, and employs multilingual platforms (Cheng *et al.,* 2024).
2. Enhance Local Governance: Entails integrating agroecological principles into farming

practices, natural resource management, and community development programs within the panchayat's planning framework (Patel *et al.,* 2023).

3. Mobilize Climate Finance: Encourage public and private investments for climate-resilient projects, supported by policies and incentives, to benefit vulnerable communities and ensure environmental sustainability (OECD, 2023).
4. Ensure Policy Convergence: Align schemes various government schemes such as MGNREGA, MIDH, and NRLM to collectively support agroecological goals. This alignment can optimize resource use, avoid duplication of efforts, and create synergies across sectors like employment, horticulture, and rural livelihoods (Maliappan and Singh, 2024).
5. Mainstream Women and Youth: targeted investments in training, skill development, and leadership programs. Such initiatives foster inclusivity, empower marginalized groups, and ensure their voices shape decision-making processes and community resilience (Ferto and Bojnec, 2024).
6. Disaster Preparedness: Integrate agroecology into risk reduction and insurance systems targeted investments in training, skill development, and leadership programs. Such initiatives foster inclusivity, empower marginalized groups, and ensure their voices shape decision-making processes and community resilience (FAO, 2019).

13. Conclusion

India's agricultural future stands at a critical juncture, where the compounded pressures of climate change, ecological degradation, and socio-economic vulnerabilities demand a transformative approach. Agroecological models, rooted in biodiversity, ecological balance, and community empowerment, have emerged as a strategic and sustainable pathway to ensuring food and nutritional security. They align ecological science with traditional knowledge and modern innovation, enabling farming systems to withstand climate shocks, restore degraded resources, and strengthen rural livelihoods. The challenges outlined, declining crop yields, heat stress, erratic rainfall, emerging pest and disease patterns, and soil degradation underscore the urgency of adopting integrated, region-specific strategies. Agroecology offers solutions through diversified cropping, integrated farming systems, indigenous seed use, natural pest management, and resource recycling. These practices not only enhance adaptive capacity but also contribute to climate change mitigation through carbon sequestration, reduced reliance on synthetic inputs, and conservation of agrobiodiversity. Kerala's experience, exemplified by initiatives such as the KERA project and the Mayyil paddy revival, illustrates

how a combination of policy support, grassroots ownership, and scientific innovation can revitalise vulnerable food systems. Clustering farmers, reviving local varieties, enhancing water-use efficiency, and strengthening extension through Farmer Field Schools and digital advisories have yielded tangible gains in productivity, resilience, and community participation. Similarly, the empowerment of women and tribal enterprises demonstrates how agroecology can simultaneously address food access, gender equity, and livelihood diversification. Climate Smart Agriculture (CSA) complements these efforts by integrating productivity, resilience, and mitigation goals, while participatory monitoring frameworks such as the Climate Resilience Index and Total Factor Productivity ensure accountability and context-specific adaptation. The cross-cutting emphasis on gender equity, food access, and smallholder integration reinforces that sustainable transformation must be socially inclusive as well as ecologically sound. Moving forward, India's agroecological transformation will require deep structural changes: reorienting agricultural research and extension towards farmer-led innovation, mobilizing climate finance, fostering policy convergence across sectors, and mainstreaming the participation of women and youth. Disaster preparedness, local governance reforms, and sustained investment in knowledge-intensive, regenerative systems will be essential. Ultimately, the shift from input-intensive to knowledge-intensive agriculture, from extractive to regenerative practices, and from top-down to community-led governance is not merely desirable; it is imperative. By embracing agroecology as a central pillar of climate resilience and food security, India can build agricultural systems that are productive, equitable, and capable of thriving in the face of an uncertain climate future.

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Advancing Climate Resilient Agriculture for Enhanced Food and Nutritional Security: Bihar's Pathways and Innovations

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Abstract

Ensuring food and nutrition security remains one of the century's defining challenges, especially for a country as vast, diverse, and populous as India. While the global population stands at 8.23 billion, nearly 2.3 billion people worldwide face moderate to severe food insecurity. The mounting climate change effects have reversed hard-won gains, nudging millions into poverty and hunger. The country finds itself grappling with enduring food and nutritional insecurity despite being one of the world's largest food producers. This chapter explores the dimensions of food and nutrition security in India. It analyzes the interplay of climate and sustainability, regional vulnerabilities (focusing on Bihar), and the promise of sustainable solutions. Though the recurring climate hazards are crippling agriculture, there is an urgent need to shift towards a holistic approach, such as climate resilient agriculture (CRA), that enhances the adaptability of farming systems to changing climatic conditions. Through this deep dive, we seek to illuminate India's pathway to securing not just caloric sufficiency, but also dietary quality and long-term resilience.

Keywords*:* Bihar, Climate-resilient agriculture, Nutritional Security, SDG, Sustainable

Introduction

Understanding Food and Nutrition Security

A. The Global and National Picture

Food security is achieved when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food. Nutrition security extends this concept, emphasizing that the food must meet individuals' dietary needs for an active, healthy life. Globally, hunger remains

distressingly widespread. Over 2.3 billion people were food insecure in 2021, and more than 3.1 billion could not afford a healthy diet a figure up by over 100 million from the prior year. India, ranked 105th out of 127 countries with a score of 27.3 (Figure 1) in the 2024 Global Hunger Index (GHI), which a 'serious' rating caused by high child wasting and stunting rates, alongside persistent gender and socioeconomic disparities (GHI, 2024).

≤9.9 Low	10.0-19.9 Moderate	27.3 20.0-34.9 Serious	35.0-49.9 Alarming	≥50 Extremely alarming

Figure 1. GHI Score for India in 2024

Figure 2 clearly depicts that in past 24 years, India's advancement on hunger and nutrition indicators moved from 38.4 to 27.3 which has been frustratingly slow.

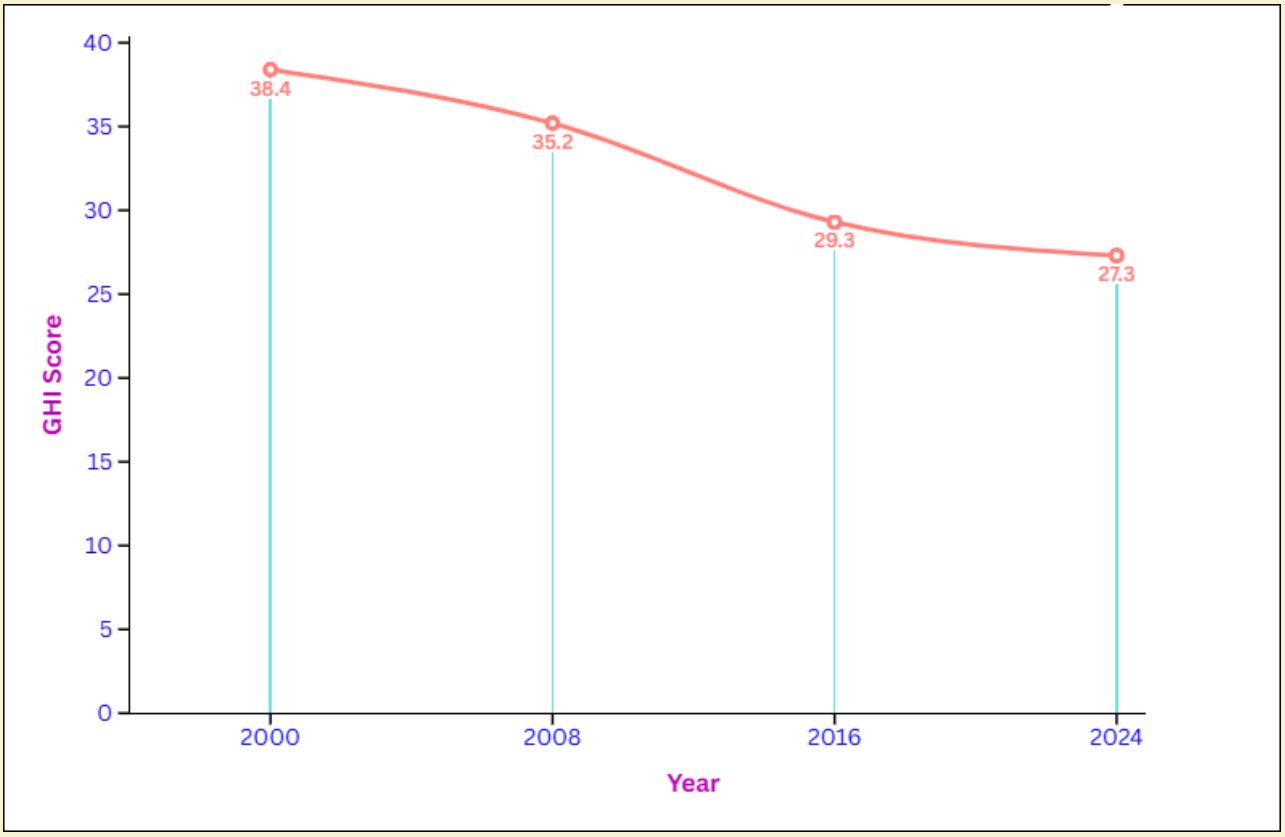


Figure 2. India position in Global Hunger Index in different years

In 2024, India continues to face serious challenges in nutrition and food security as reflected in the Figure 3. The prevalence of undernourishment has reached 13.7% of the population, indicating that a significant portion lacks sufficient caloric intake for healthy living. Child malnutrition remains deeply concerning, with 35.5% of children under five experiencing stunted growth Drishti (2025) and 18.7% suffering from wasting. Additionally, the under-five child mortality rate, though much

improved over recent decades, stands at 2.9%, illustrating that the complex issue of hunger and undernutrition continues to impact young lives across the country.

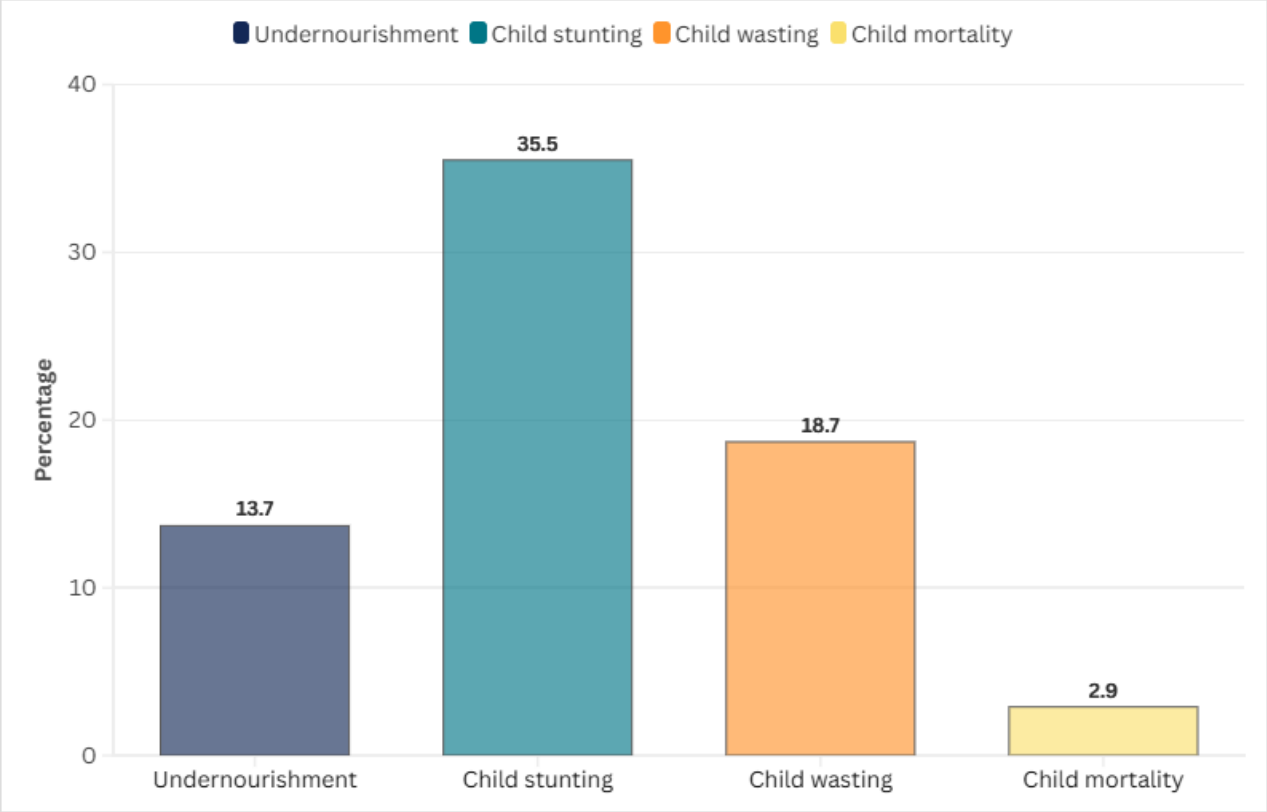
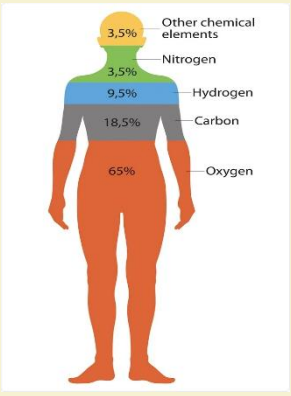


Figure 3. Serious challenges due to nutrition and food insecurity

B. Nutritional Requirements and Dietary Patterns



A human body contains oxygen, Carbon, hydrogen, Nitrogen etc. in various quantity. So nutrition requirements for an average adult, extrapolated per year, illustrate the breadth of a healthy diet. Despite this, Indian diets remain heavily cereal-based, with low per capita consumption of pulses, vegetables, and animal-source foods, a major factor in widespread micronutrient deficiencies (hidden hunger) (KPMG, 2025).

For a family of five, recommended annual requirements would be:

Food Group	Adult Annual Requirement	Five-member Family (Annual)
Cereals	175kg	875kg
Pulses	19kg	95kg
Oilseeds	25kg	125kg
Vegetables	128kg	640kg

Fruits	45kg	225kg
Milk	110kg	550kg
Meat (substitute for milk)	24kg	120kg
Tubers	36kg	180kg
Eggs	180 (pieces)	900 (pieces)

Root Causes and Structural Barriers

A. Poverty and Socioeconomic Inequality

Widespread poverty underpins food and nutrition insecurity in India. Marginalized groups such as rural poor, tribal populations, scheduled castes experience disproportionately high rates of hunger and stunting. Regional disparities further exacerbate these challenges: states like Bihar, Jharkhand, and Uttar Pradesh record far worse indicators than urban, wealthier regions. Unemployment, low agricultural wages, and the informal economy limit households' ability to access nutritious food on a regular basis. According to recent government statistics, Bihar's per capita income stands at just ₹5,722, substantially below India's national average of ₹22,946.

B. Food Availability and Access

While India is a net food producer, patchy infrastructure, post-harvest losses, and price volatility often disrupt supply chains. Seasonal shortfalls and hoarding can make staples unaffordable, especially for the urban and rural poor. Pulses, fruits, and vegetables are often out of reach for millions due to cost.

C. Dietary Diversity and Cultural Patterns

Indian diets are often monotonous, centering on rice or wheat, with limited protein and micronutrient intake. Changing dietary habits, junk food consumption, and inadequate nutrition education compound the problem. Anaemia (especially among women and children) and growing obesity in urban areas reveal a dual burden of malnutrition (Forum, 2025)..

D. Health, Sanitation, and Education

Malnutrition is not solely a matter of food. Poor sanitation, open defecation, and lack of clean drinking water exacerbate infection rates in children, impeding nutrient absorption. Low literacy, especially among women, undermines effective nutrition and health interventions.

E. Environmental and Climatic Vulnerabilities

Climate change represents the biggest long-term threat to food and nutrition security. Recent projections indicate that, if greenhouse gas emissions remain unchecked, India will surpass the critical 1.5°C warming threshold within the next two decades. Each 1°C rise in temperature is expected to boost rainfall extremities by 7%. Additionally, the carbon dioxide concentration in the atmosphere has reached its highest level in over 2 million years (Mohapatra, 2025). Indian agriculture, with rising temperatures, rainfall extremes, and record-high atmospheric carbon dioxide posing multiple challenges to crop productivity and food security. Each 1°C rise in temperature leads to increased heat stress on crops, damaging flowering, pollination, and grain maturity. For staple crops like wheat and rice, a projected temperature increase of 2.5–4.9°C could cause wheat yields to fall by 41–52% and rice yields by 32–40%. Higher temperatures also speed up crop cycles and worsen water scarcity, making agriculture less reliable for millions. More frequent and erratic rainfall events, including intense monsoons and unseasonal downpours, have caused floods and droughts that damage crops like wheat, rice, and maize. Such events create variability in yields and reduce farmer incomes, with crop losses as high as 20% during major rainfall events. Timing of floods is critical: early rains may aid sowing while late floods ruin standing crops. While elevated CO_2 levels can boost short-term plant growth and improve water-use efficiency, they also reduce the nutritional quality of produce by lowering protein, iron, and zinc in grains. Increased CO_2 supports growth of certain weed species, making weed management harder and further straining food security.

Future Demand for Food Grains

India's growing population, projected to rise from 1.21 billion to 1.7 billion by 2050, will significantly increase the country's future food requirements. To meet the nutritional needs of this expanding population, the demand for food grains is expected to surge from the current 284.95 million tonnes to approximately 400 million tonnes by 2050. This sharp rise in food grain demand will pose critical challenges for Indian agriculture, requiring substantial improvements in productivity, resource management, and sustainable farming practices to ensure food security for all. But the so-called modern agriculture fails to fulfils the demand of food grains as shrinking in net cultivable area due to over exploitation of population, increasing environmental pollution, depleting ground water table, increasing cost of production, low farm income, increasing unemployment, decline in agricultural productivity, especially in rain-fed and ecologically sensitive states like Bihar, is under siege from rising temperatures, erratic monsoons, floods, and droughts.

Regional Hotspots: Bihar's Double Whammy

The state Bihar is uniquely and repeatedly afflicted by two contrasting natural disasters i.e. floods and droughts, often within the same year and sometimes even simultaneously. Northern districts of Bihar are especially vulnerable to devastating floods, frequently caused by overflowing rivers and heavy rainfall from the monsoon, while southern districts suffer from droughts due to scanty and erratic rainfall. In some years, like 2019, both disasters occur together: over a dozen districts experienced flooding, while nearly two dozen faced drought, with some districts declared both flood and drought-affected at once. Bihar is an agriculture dominated state where more than 70% of the state's population relies on farming for income, food, and social security. 80-85% of the population lives in rural areas and nearly 60 % of the cultivated area is rainfed. So, these climatic events cause extensive damage to agriculture, infrastructure, and livelihoods, making Bihar a "hotspot" for climate-driven disasters (BSDMA, 2016; Kumar,2019; Khan, 2024). According to data from the Bihar State Disaster Management Authority (BSDMA) and NITI Aayog, Bihar incurs an estimated ₹6,000 to ₹8,000 crore in agricultural losses annually due to climate-related shocks. Climatic challenges like erratic and unpredictable monsoon patterns, frequent dry spells, droughts, floods, and submergence directly affect poverty levels in Bihar. The state's poverty rate of 33.74% is significantly higher than the national average of 21.92%, while its per capita income, at Rs. 5,722, remains well below the national average of Rs. 22,946. According to the economic survey 2021 report highest area i.e. 68.08 Lakh ha is flood prone land and only 0.97 Lakh ha area under chaur land. But due to frequent climatic events all the areas are affected by both floods and droughts sometimes.

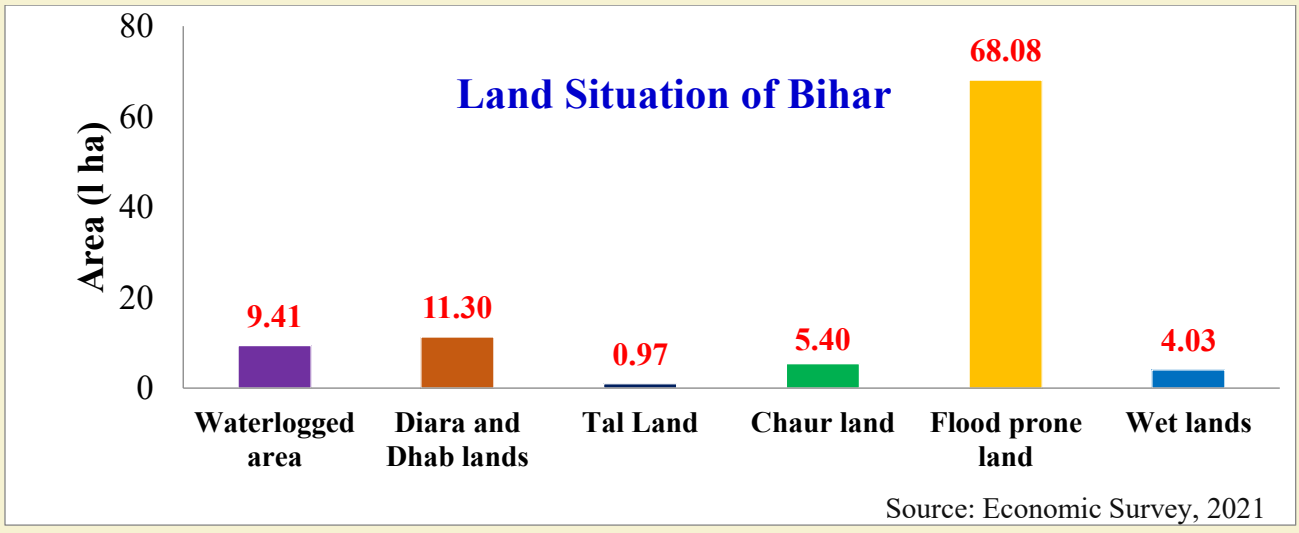


Figure 4. Various land situations of Bihar

But amidst these challenges of the recurring cycle of floods and droughts crippling agriculture and livelihoods in Bihar, there is an urgent need to shift towards a holistic approach such as climate resilient agriculture (CRA), that enhances the adaptability of farming systems to changing climatic conditions.

Efforts towards Climate Resilient Agriculture in Bihar

Bihar's most important public agricultural institutions i.e. Dr. Rajendra Prasad Central Agricultural University (RPCAU) in Samastipur has released 23 stress-resilient crop varieties, including rice, maize, and pulses suited to Bihar's agro-climatic zones (RPCAU, 2024) enhancing coping mechanism of farmers against climate-induced risks in agriculture over the past five years. Other than this the university has adopted climate smart agriculture project, National Initiative (Innovation) on Climate Resilient Agriculture (NICRA), Solar trees/ Boat Mounted Solar Pumping Systems, community irrigation project, Water Harvesting cum Recharge Structure, Carbon -smart agriculture, custom hiring centers which have significantly elevated Bihar's scientific and grassroots response to climate risks.

Results

Through adoption of the interventions, Bihar is visualizing a sustainable, food and livelihood secure and climate smart future ahead. Climate-smart agriculture (CSA) is a holistic approach to farming that integrates adaptation, sustainability, and innovation. It aims to boost productivity while improving resource efficiency and reducing exposure to weather risks, and lowering greenhouse gas emissions It has already demonstrated tangible benefits, enhanced farm income, supporting ecosystem services. It must become a core pillar of Bihar's economic and climate policy. According to estimates by NICRA and RPCAU, scaling climate smart agriculture across Bihar could raise the state's Gross State Domestic Product (GSDP) by 2–3% over the next five years (ICAR, 2023). This happens through more stable farm output, higher rural demand, and reduced volatility in agri-based trade.

Climate Smart Agriculture Interventions

S.N.	Category	Interventions
1	Water Smart	Direct Seeded Rice, Maize Based System, Raised Bed, Precision Land Leveling, Alternate Wetting and Drying in Rice, Bunding, Micro-Irrigation, Irrigation Scheduling, Crop Varieties, Residue Mulching, Cropping System Optimization

2	Nutrient Smart	SSNM, Nutrient Expert, Decision Support Tool for Maize and wheat,Green Seeker, Legume Integration, Leaf Color Chart
3	Carbon Smart	No Tillage, Residue Management, Agroforestry
4	Energy Smart	No Tillage, Residue Management, DSR, Cropping System Optimization, Eliminate Puddling in Rice
5	Weather Smart	Weather Forecast, Index based Insurance, Seeds for Needs, Crop Diversification
6	Knowledge Smart	ICT, Gender Empowerment, Capacity Development

Interventions of NICRA

Climatic Vulnerability	Identified Problems	Key Interventions (NICRA)
Low Rainfall	Reduced recharge, water table decline	Reservoir renovation, drought-tolerant seeds
Late Monsoon Onset	Delayed transplanting, lower yields	Direct Seeding Rice, Short-duration varieties
Failure of Oct. Rains	Late rabi sowing, lower output	Late-sown varieties, conservation tillage
Moisture Stress	Fertilizer inefficiency	Mulching, higher organic matter use
Salinity Build-up	Soil degradation	Salt-tolerant crops, green manuring

After renovation of ponds and water bodies 31074 cubic meter water available for irrigation, and 63 ha area brought under assured irrigation in adopted villages. In- situ moisture conservation through Land leveling, mulching and organic approaches increases yield of brinjal 288.75 q/ha, saving in irrigation water by 1 ha cm, and moisture retention increased by 8 days.

Impact of CRA Programme on productivity of paddy

From the figure 5 it is evident that the productivity of paddy has increased 25.5 q/ha (2017-18) to 40.5 q/ha (2022-23) after the intervention of climate resilient agriculture programme.

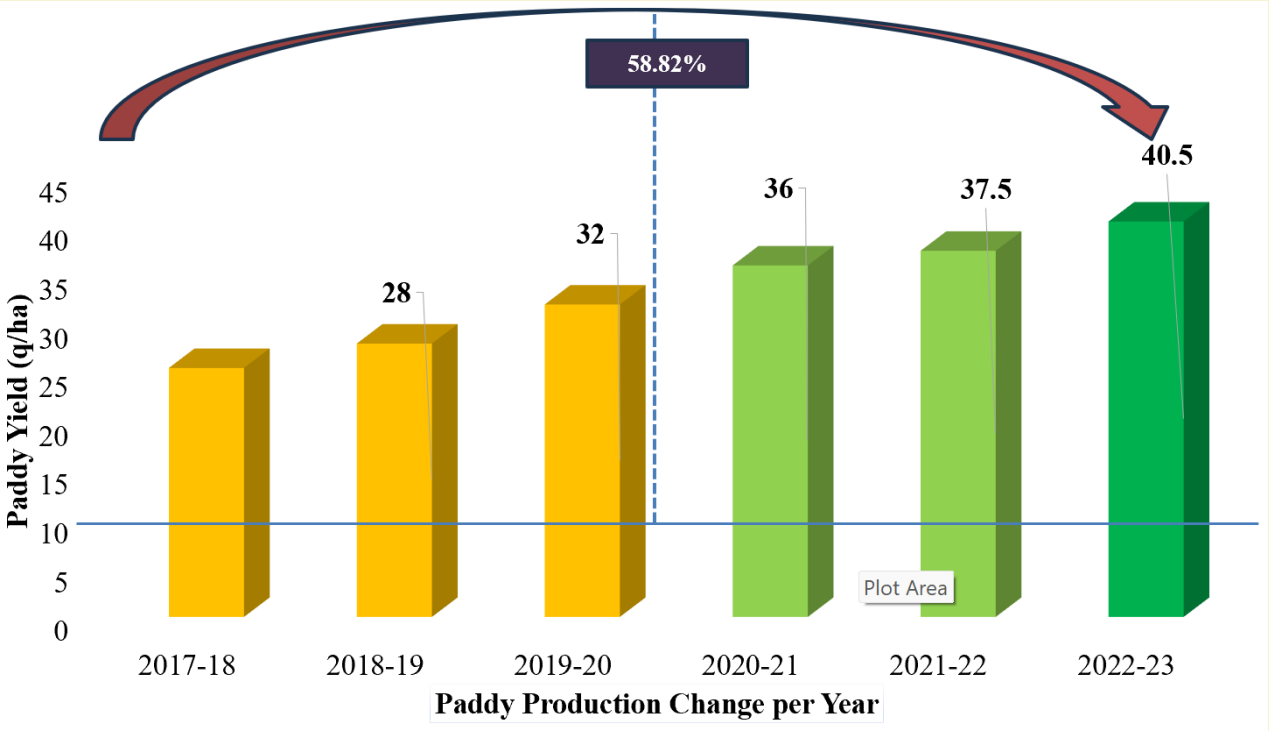


Figure 5. Impact of CRA Programme on productivity of paddy

Also, food security was gained through climate smart practices explained in figure 6.

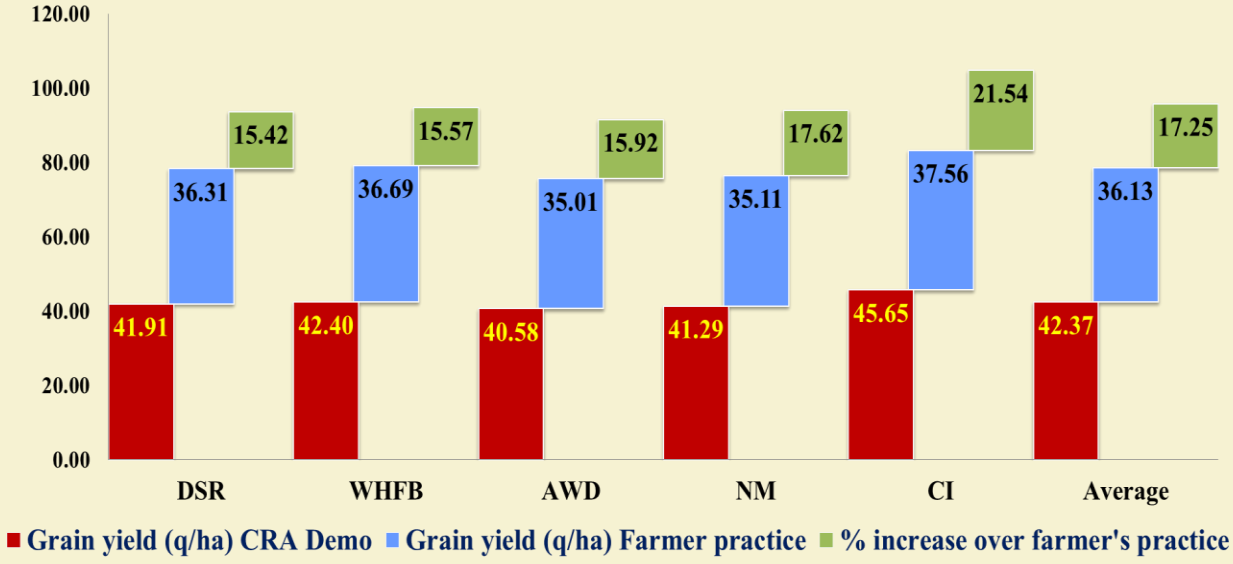


Figure 6. Climate Smart Practices vis-à-vis Food Security

Key Findings

1. CRA technologies helped in improving productivity by 35% and income by 50%, despite climate related risks

2. Zero Tillage (ZT) systems helped in advancing the planting dates of wheat, by at least 7-10 days, by saving the land preparation time. It has been found that ZT rice followed by ZT wheat provides better net returns to small and marginal farmers.
3. Water, nutrient, energy, labour and time use efficient (by at least 20%) climate CRA practices with 35% higher yields, and improved soil health and reducing environmental footprint by 25%.
4. Achieving carbon-friendly intensification and systems resilience: ZT plays a significant role in minimizing emissions of GHGs.
5. CRA programme is increasing productivity of both rice and wheat in adopted agroclimatic zone making Bihar as food and nutritional secure state.

Conclusion

India's journey toward eradicating hunger and malnutrition is fraught with complexity but full of promise. The interplay of poverty, environmental change, dietary transitions, and systemic gaps means the path is neither linear nor quick. To move up the Global Hunger Index and, more crucially, to ensure the health and dignity of every citizen, the country needs to further invest in nutrition-sensitive agriculture and climate-resilient farming through inclusive policies and focused outreach. Climate-smart agriculture offers a path forward that is scientifically grounded, economically sound, and socially just. It improves yields and dignity while supports growth and stability. Moreover, it empowers vast majority of marginal farmers and farm women. It prepares Bihar for a future where floods may be fiercer and droughts deeper—but where its farmers stand ready. With the right investments in science, systems, and cross-border cooperation, resilience can become Bihar's next green revolution.

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Gender-Inclusive Nutri-Sensitive Agriculture for Improved Family Nutrition

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ABSTRACT

Gender-inclusive, nutrition-sensitive agriculture offers a transformative pathway to improve family nutrition and build resilient food systems. Women play a central role in agricultural production and household food decisions, yet their contributions often remain undervalued due to limited access to resources, land, technology, and capacity-building opportunities. By integrating a gender perspective into agricultural strategies, nutrition outcomes can be significantly enhanced, addressing the triple burden of malnutrition—undernutrition, hidden hunger, and overnutrition. Drawing on NFHS-5 data, Global Hunger Index, and the Global Gender Gap Index, it analyzes gender and nutrition disparities in India, situating them in a global context. Innovative approaches such as the Gender-Sensitive Agri-Nutri (GSAN) model and the Nutri-Smart Village initiative, which promote crop diversification, biofortification, millet cultivation, and household nutrition practices. Institutional mechanisms, including Self-Help Groups, women's collectives, and farmer producer organizations, are identified as vital for scaling these interventions. Emphasis is placed on skill development, nutrition literacy, drudgery reduction, and entrepreneurship for empowering women farmers. Aligning such interventions with SDGs on Zero Hunger, Gender Equality, and Good Health will pave the way toward a nutrition-smart, gender-equitable future.

Keywords: Dietary diversity, Gender-sensitive agriculture, GSAN model, Malnutrition, Nutrition security, Nutri-Smart Village, Women empowerment

Global food and nutrition security means ensuring that everyone has reliable access to safe, nutritious, and sufficient food that supports a healthy, active life. It is a multifaceted concept that includes not only food availability but also food access, utilization, and the stability of these factors

over time. Achieving this security means more than producing enough food globally; it requires ensuring vulnerable populations can reliably obtain and effectively use nutritious food to support overall health and development (FAO, IFAD, UNICEF, WFP and WHO, 2025). The global food and nutrition security landscape is shaped by a variety of challenges, including climatic disruptions, conflicts, economic instabilities, and inefficient supply chains. These challenges have resulted in high food price volatility, which disproportionately impacts low-income countries where inflation rates for food often exceed overall inflation, further limiting access for vulnerable groups (World Bank, 2025a). Additionally, malnutrition remains a pervasive issue, encompassing under nutrition, micronutrient deficiencies, as well as overweight and obesity, affecting millions worldwide and undermining global health outcomes (UN, 2025). To address these interconnected issues, international bodies such as the World Bank, FAO, United Nations, and the Global Alliance for Food Security have launched various initiatives aimed at enhancing resilience, improving market access for small-scale producers, promoting social protection programs, and enabling climate-smart agricultural practices (World Bank, 2025b). Sustainable solutions for global food and nutrition security require coordinated efforts across multiple sectors to build food systems that are resilient, inclusive, and capable of adapting to future shocks. Only through integrated approaches that combine immediate relief with long-term structural reforms can the world ensure equitable access to nutritious food for all and ultimately achieve the goal of zero hunger. This expanded perspective demonstrates that addressing global food and nutrition security is not merely a matter of increasing food production but requires systemic transformation across agricultural, economic, social, and environmental domains to mitigate risk and promote long-lasting well-being for all populations.

Linkage between Agriculture, Gender, and Nutrition

Agriculture, gender, and nutrition are deeply interconnected sectors that influence each other in complex ways, shaping food security and nutritional outcomes globally. Gender mainstreaming in nutrition-sensitive agriculture interventions has become a pivotal approach to improve women's empowerment, household nutrition, and overall agricultural productivity. Women, who constitute a significant proportion of the agricultural workforce—up to 43 percent (FAO, 2011) in many developing countries—play central roles not only in food production but also in food processing, preparation, and household nutrition decision-making. However, persistent gender inequalities limit their access to resources such as land, credit, training, technology, and decision-making power, which diminishes their potential impact on nutrition outcomes. Nutrition-sensitive agricultural

programs that integrate gender considerations aim to improve both food availability and dietary quality by empowering women as key agents of change. Moreover, interventions that combine agricultural training with nutrition education have demonstrated improved child and women's nutritional status, reinforcing the value of integrated approaches (FAO, 2012). The Agriculture, Nutrition, and Gender Linkages (ANGeL) project in Bangladesh provides empirical evidence that bundling nutrition and agriculture training leads to sustained consumption impacts and increased women's empowerment. Importantly, the project shows how empowering women in agricultural production and increasing their control over income can improve household nutrition while fostering resilience (IFPRI, 2025). Income control by women is linked to higher household food security and improved dietary diversity, as women tend to prioritize spending on food, health, and education (Harris-Fry *et al.,* 2020). At a broader societal level, enhancing gender equity in agriculture contributes not only to better nutrition outcomes but also to poverty reduction and economic equality. However, the interaction between gender dynamics and nutrition outcomes is context-specific, influenced by factors such as ethnicity, socio-economic status, and local cultural patterns and norms. Consequently, nutrition-sensitive agricultural interventions must undertake formative gender analyses tailored to local contexts to design effective programs that maximize nutritional and empowerment impacts (Kjeldsberg *et al.,* 2018). Furthermore, gender-sensitive approaches in agriculture and nutrition extend to transforming social norms and roles. The pathway from agriculture to improved nutrition is gendered and complex, requiring integrated interventions that empower women, reduce gender inequalities, and address socio-cultural barriers. Mainstreaming gender in nutrition-sensitive agricultural policies and programs is a critical strategy to enhance food security, nutritional status, and women's empowerment, ultimately contributing to SDGs linked to hunger eradication and gender equality.

Global Food System Challenges

Global food systems face a multitude of complex and interconnected challenges that threaten the ability of millions to access sufficient, safe, and nutritious food. A major challenge is the persistent and rising acute hunger, with more than 343 million people experiencing acute levels of food insecurity (World Food Programme, 2025), driven largely by conflict, economic shocks, climate extremes, and forced displacement. Conflict disrupts agricultural production, infrastructure, and markets, pushing vulnerable populations toward malnutrition and starvation, while climate change intensifies weather shocks that further undermine food production and exacerbate environmental

degradation globally. Food systems are also exposed to economic vulnerabilities and market volatility. Low-income countries spend a disproportionately large share of their export revenue on food imports, making them highly susceptible to external shocks such as the COVID-19 pandemic or geopolitical conflicts like the war in Ukraine. These disruptions elevate food prices and reduce availability, often disproportionately affecting poor and marginalized communities that already struggle with isolation and limited access to nutritious food. Even when food is sufficient at a national level, inefficiencies in post-harvest handling, storage, and transportation result in significant food loss and waste, which worsens food insecurity and volatility in prices. Another critical challenge lies in the growing nutrition crisis, marked by the coexistence of under nutrition, micronutrient deficiencies, and a global rise in overweight, obesity, and diet-related non-communicable diseases. Nutrition-sensitive food environments remain deficient, with unhealthy diets increasingly prevalent worldwide, especially in low- and middle-income countries.

Fig. 1. Global Food System Challenges

The environmental sustainability of food systems is under increasing pressure due to unsustainable natural resource management. Climate change impacts—including extreme heat, droughts, flooding, and unpredictable rainfall—pose serious risks to agriculture and exacerbate existing vulnerabilities in food systems. The global food system challenges are multidimensional—

combining conflict, climate change, economic shocks, nutrition crises, environmental degradation, and social inequalities. To meet the growing demands and ensure food security by 2030, urgent, coordinated actions emphasizing resilience, sustainability, equity, and nutrition are required. This includes strengthening food system infrastructure, supporting smallholder farmers, improving market functioning, promoting healthy diets, and advancing inclusive policies that empower vulnerable populations.

Sustainable Food Systems for Nutrition Security

Achieving nutrition security in the twenty-first century requires rethinking how food systems are structured, governed, and sustained. A sustainable food system ensures food security and nutrition for all while protecting the economic, social, and environmental resources needed for future generations. This implies that food systems must simultaneously enhance human health, preserve ecosystems, and be socially inclusive (UN, 2022). Food security, as outlined by the Sustainable Development Goals (SDGs), encompasses not only the availability of food but also its access, utilization, & stability (UN-SDG, 2022). While agricultural production has expanded globally, dietary transitions toward energy-dense, nutrient-poor foods have exacerbated malnutrition and diet-related non communicable diseases. Sustainable food systems aim to reverse this trend by diversifying agricultural production, promoting local and traditional foods, and integrating nutrition goals into food policies (WHO, 2022). The Food and Agriculture Organization proposes that sustainable food systems are critical for balancing environmental health with nutritional outcomes, emphasizing agro ecology, reduced food waste, and resilience against climate change (FAO, 2018). Equally, the World Health Organization stresses that food systems must address the double burden of malnutrition—where under nutrition coexists with obesity—by supporting access to safe, diverse, and affordable diets. This involves systemic reorientation, including investment in value chains that prioritize nutrient-rich crops, fortification strategies, and the reduction of ultra-processed foods. Furthermore, sustainable food systems involve inclusive governance that empowers smallholder farmers, women, and marginalized groups who are critical to food production yet often remain food-insecure themselves (SUN, 2021). Nutrition security through sustainable food systems requires a paradigm shift from production-focused models to ones that prioritize human and planetary well-being. This systemic transformation is essential to achieving SDG 2, "Zero Hunger," and ensuring resilient, healthy, and equitable food futures for all.

Malnutrition: The Triple Burden

Malnutrition refers to both under- and overconsumption of nutrients, including under nutrition (stunting, wasting, underweight), over nutrition (overweight, obesity), & hidden hunger (micronutrient deficiencies). Tackling malnutrition in all its forms is central to achieving the Sustainable Development Goal 3 (SDG-3): "Good Health and Well-being," which includes ending all forms of malnutrition by 2030. However, with the current pace of progress, and as highlighted in global reports, eliminating malnutrition by 2030 remains a significant and unresolved challenge for most nations. The persistence of under nutrition alongside rapidly growing overweight and obesity points to a complex triple burden of malnutrition.

Forms of Malnutrition

Under nutrition: Characterized by insufficient nutrient or energy intake, manifesting as stunting, wasting, and underweight—conditions that impair growth and development.

Over nutrition: It refers to an unbalanced or excessive intake of nutrients that can result in overweight, obesity, and diet-related non-communicable diseases.

Hidden Hunger: Denotes deficiencies in essential vitamins and minerals (micronutrient deficiencies), which often show no immediate symptoms but undermine immunity, productivity, and well-being.

Maternal and Child Health Issues

Malnutrition's impact is especially severe among mothers and children:

- Anaemia: Widespread, particularly affecting women of reproductive age and young children.
- Low Birth Weight: Largely stemming from poor maternal nutrition, associated with infant morbidity and long-term health risks.
- Stunting and Wasting: In India, 35.5% of children under 5 are stunted and 18.7% are wasted, among the highest globally (NFHS, 2019-21a).
- Suboptimal Breastfeeding and Child Feeding: Poor practices remain a major driver of early childhood under nutrition.

Table 1: Global Statistics (with reference to India)

SI. No.	Organization/ Report	Key Indicators/ Findings	Data	Year
1.	Global Hunger Index URL:https://www.globalhungerindex.org/	GHI Rank & Score; Child Stunting/Wasting /Mortality	Rank: 105/127; Score: 27.3	2024
			Child Wasting: 18.7%	2019-2023
			Child Stunting: 35.5%	2019-2023
			Under-five Mortality: 2.9%	2022
			Undernourishment: 13.7%	2021-2023
2.	World Bank URL: India Overview: Development news, research, data | World Bank	Child Malnutrition Prevalence	One of the world's highest child malnutrition, with 67 percent for children in the 6-59 months age group.	2024-25
3.	National Family Health Survey (NFHS-5), Ministry of Health, India URL: National Family Health Survey (NFHS-5), 2019-21: India	Child Stunting, Wasting	Stunting: 36% Wasting: 19%	2019-21

4.	FAO, IFAD, UNICEF, WFP, and WHO. 2025. The State of Food Security and Nutrition in the World 2025 – Addressing high food price inflation for food security and nutrition. URL:https://openknowledge.fao.org/server/api/core/bitstreams/e612e779-ec47-44c2-a3e0-499569c3422d/content	Diet Affordability	40.4 % proportion of the population unable to afford a healthy diet, i.e., 586.5 million people are unable to afford a healthy diet.	2024
		Child Stunting, overweight	37.4 million children (1-5 Years) are stunted 4.2 million children (1-5 Years) are overweight	2024
		Adult Obese	71.4 million adults (>18) are obese	2022
		Anaemia	203.5 million women (15-49 Years) affected by anemia	2023
		Low Birth weight	6.3 million babies with low birth weight	2022

The 3 R's in Family Farming

The framework of the 3 R's in Family Farming—Recognition, Redistribution, and Representation—serves as a vital perspective for examining gender equity in agriculture. Empirical evidence consistently shows that women play a vital role in agriculture, as shown by evidence of their involvement in livestock care, post-harvest processing, sowing, weeding, harvesting, and in safeguarding household food security. However, these contributions often remain invisible in policy and practice. The first dimension, recognition, emphasizes the need to acknowledge women and men as equal partners in family farming, thereby challenging the widespread tendency to view women's labour as secondary or supplementary.

The second dimension, redistribution, underscores the structural inequalities in access to productive resources such as land, credit, extension services, technology, and training. Addressing these disparities through gender-responsive policies is crucial for enhancing agricultural productivity, improving household resilience, and achieving broader rural development objectives. The third dimension, representation, highlights the importance of incorporating women's voices in decision-making processes at both household and community levels. Evidence indicates that women's participation in decision-making improves outcomes in nutrition, education, and sustainable resource management. Collectively, the 3 R's framework promotes a transformative approach to family farming by ensuring equity, inclusivity, and sustainability, while also aligning with global development priorities such as the Sustainable Development Goals (SDGs).

Missing Link between Agriculture and Nutrition

In the Indian context, there exists a discernible disconnect between agriculture and nutrition, despite the nation's notable accomplishments in food production. Although India has achieved remarkable progress in augmenting agricultural output, particularly in staple crops such as rice and wheat since the Green Revolution, this emphasis on quantity has not sufficiently addressed the nutritional needs of the population (Sarkar & vanLoon, 2015). The country continues to grapple with pervasive malnutrition, child stunting, and micronutrient deficiencies, ranking poorly on the Global Hunger Index and exhibiting persistent disparities between agricultural policy and nutritional outcomes. The primary factor contributing to this disconnect is the predominance of staple crops in agricultural policy and subsidies, which has inadvertently marginalized the cultivation and consumption of nutrient-dense foods like pulses, fruits, and vegetables. Economic disparities further exacerbate this issue, as economically disadvantaged households often have limited access to diverse diets and consequently rely on calorie-dense but nutrient-deficient foods.

India's Nutritional Security: Challenges at the Crossroads of Agriculture, Climate, and Policy

The Green Revolution's Mixed Legacy

India's agricultural policies, profoundly influenced by the Green Revolution, have historically emphasized the cultivation of staple crops, particularly wheat and rice. While this strategy effectively secured national food security by augmenting calorie availability, it has inadvertently resulted in a dietary imbalance. The disproportionate emphasis on cereals has marginalized the production and consumption of diverse, nutrient-rich crops such as pulses, fruits, vegetables, and

millets. Consequently, India confronts a dual challenge of food abundance and nutritional inadequacy. This paradox is evident in the Global Hunger Index (2023), where India ranked 111th out of 125 countries, underscoring the persistence of undernutrition and micronutrient deficiencies despite sufficient caloric intake. Recent initiatives, such as the renewed emphasis on millets during the International Year of Millets (2023), represent essential corrective measures. Nevertheless, to achieve sustainable dietary balance and improved public health, it is imperative to implement a comprehensive policy transformation that integrates nutritional diversity into both agricultural planning and food distribution systems.

Climate change intensifies India's nutrition challenges by reducing both food quantity and quality through rising temperatures, erratic rainfall, droughts, and floods, which lower crop yields, degrade soil fertility, and diminish nutrient content, especially in staples like wheat and rice. India ranks seventh on the Global Climate Risk Index (2021), facing increased food prices that disproportionately impact vulnerable populations and exacerbate food insecurity. These environmental pressures also disrupt farming communities' livelihoods, increase costs, and deepen poverty, especially among smallholders and women. With over 65% of farmland rain-fed, changing rainfall patterns severely threaten agricultural stability, soil health, and water availability, further contributing to food scarcity and nutritional deficiencies.

Additionally, despite improvements in school enrolment, India faces significant gaps in nutritional literacy. Many lack awareness of dietary diversity, balanced nutrition, and infant feeding practices, which undermines efforts to improve public health. Programs like mid-day meals have improved nutrient intake but often lack long-term impact. Nutrition education is limited, with few higher education institutions offering specialized training, and cultural attitudes often confine nutrition knowledge to illness treatment rather than prevention. Strengthening the integration of nutrition into education, empowering consumers to understand food labels, and promoting climate-resilient agricultural strategies are essential to address food security, improve nutrition outcomes, and break intergenerational cycles of malnutrition in India.

Hence, in order to connect agriculture with gender and nutrition, a Gender Sensitive Agri - Nutri (GSAN) Farming System Model has been conceptualized.

Gender-Sensitive Agriculture (GSA) encompasses agricultural strategies, policies, and practices that consciously recognize and address the distinct roles, responsibilities, needs, and constraints

experienced by men and women within farming systems. In contrast to traditional agricultural development, which often treats farmers as a uniform group, GSA acknowledges the existing gender disparities in access to resources, decision-making authority, and the benefits derived from agricultural interventions. Gender-sensitive agriculture (GSA) is integral to achieving comprehensive food and nutrition security by acknowledging and addressing the distinct needs, roles, and contributions of both women and men within agricultural systems (Huyer & Chanana, 2021). GSA prioritizes the diversification and sustainability of food systems, ensuring that production not only increases in quantity but also enhances in quality to satisfy diverse nutritional requirements. By concentrating on fortification and the production of nutrient-dense foods, GSA addresses micronutrient deficiencies prevalent in numerous communities. Furthermore, gender-sensitive strategies enhance livelihoods by fostering commercialization and marketing opportunities accessible to all, with a particular focus on women, who frequently encounter greater obstacles to market entry. GSA also facilitates the implementation of complementary and supplementary therapeutic feeding programs, which are crucial for vulnerable populations, including children and pregnant women. Significantly, it integrates agriculture with other sectors—such as health, sanitation, and education—to address the multifactorial causes of malnutrition. Furthermore, GSA promotes gender-equitable roles within agricultural market systems, aiming to empower women and ensure that both genders benefit equally from agricultural advancements (Malapit *et al.,* 2021). Fundamentally, gender-sensitive agriculture is essential for developing resilient, inclusive, and nutrition-focused food systems that can effectively combat hunger and undernutrition in the long term.

Potential Approaches for Nutrition Smart India

Potential strategies for Nutrition Smart India encompass a multifaceted approach that integrates both food-based and non-food-based interventions to improve nutritional outcomes nationwide. Food-based strategies prioritize the cultivation and availability of nutrient-rich crops at the agricultural level. These strategies emphasize connecting farmers to markets and value chains at the farm gate, ensuring that the nutrient content of food is preserved during cooking, storage, and processing at the household level. This comprehensive focus enhances the accessibility and consumption of diverse and nutrient-dense foods, directly addressing malnutrition and micronutrient deficiencies prevalent in India.

Non-food based approaches complement these efforts by empowering women with gender-friendly tools and technologies aimed at improving livelihoods, reducing labor and time burdens, and generating income, especially through improved livestock husbandry and sustainable agricultural practices. These measures contribute significantly to improved nutrition and health outcomes in rural households by enhancing women's roles and capacities within agricultural systems.

To truly revolutionize our approach to nutrition and agriculture, it is imperative that we adopt a comprehensive set of strategies that promise transformative change. By championing innovative nutrition-sensitive agricultural practices and fortifying food security, we can lay a robust foundation for a healthier future. Establishing sound governance and policies is not just beneficial but essential, as is resolving value chain and village trade issues that hinder progress. Enhancing maternal and child nutrition is a non-negotiable priority, and improving complementary feeding and nutrition literacy is crucial for long-term success. Furthermore, empowering women's institutions such as Self-Help Groups, Farmer Interest Groups, and Farmer Producer Organizations through capacity development is vital. Together, these strategies are not merely steps but leaps toward a Nutrition Smart India, fostering sustainable, inclusive, and nutrition-sensitive agriculture that will transform food systems and elevate public health across the nation.

Initiatives of ICAR

Nutrition-Sensitive Agriculture

Agriculture and nutrition are intrinsically linked; however, agricultural development has historically emphasized yield maximization and calorie sufficiency over dietary quality and nutritional well-being. While this production-centric model has been instrumental in alleviating hunger, it has been less successful in addressing persistent malnutrition, micronutrient deficiencies, and the increasing prevalence of diet-related chronic diseases. Nutrition-sensitive agriculture (NSA) has emerged as a transformative approach that explicitly incorporates nutritional objectives into agricultural systems, ensuring that farming not only provides sufficient food but also delivers adequate nourishment for improved health outcomes.

Nutrition-sensitive agriculture emphasizes the cultivation of a wide array of nutrient-rich crops, such as pulses, fruits, vegetables, and millets, while also advocating for the adoption of biofortified and climate-resilient varieties. Nutrition-sensitive agriculture focuses on crop diversification, sustainable practices, and the enhancement of local foods through bio fortification to address hidden

hunger. Biofortified varieties, such as zinc-rich rice, iron-rich pearl millet, and vitamin A-enriched sweet potato, improve dietary quality at the household level. By incorporating these nutrient-dense foods into culturally relevant diets, exemplified by the "Nutri Thali" concept, balanced meals are achieved, combining local produce with enhanced nutrition, thereby bolstering food security and community health.

The significance of NSA is increasingly evident in the context of climate change, which poses a threat to both the availability and nutritional quality of food through unpredictable weather patterns, reduced yields, and escalating food prices. By promoting the adoption of climate-smart, nutrition-oriented practices, NSA enhances resilience within food systems while improving their capacity to provide healthy diets. This integrated approach is closely aligned with global development priorities, including the Sustainable Development Goals, particularly those related to zero hunger, good health, gender equality, and climate action.

Institutional Mechanisms for Promoting Gender-inclusive Nutri-Sensitive Agriculture

The prevalence of malnutrition in India constitutes a triple burden, characterized by the concurrent presence of overnutrition, undernutrition, and hidden hunger resulting from micronutrient deficiencies. This complex issue highlights the necessity for agriculture to transition from production-centric policies to a comprehensive, nutrition-sensitive approach. Women farmers, as key contributors to agricultural activities, play a crucial role in bridging the gap between agricultural development and enhanced nutrition outcomes. Their participation can facilitate multidimensional progress, addressing both malnutrition and agricultural productivity. Current agricultural policies frequently prioritize enhancing farm production and increasing incomes, often inadvertently neglecting the critical importance of nutrition. This oversight is particularly concerning for small and marginal farm families, who constitute the majority in rural India. For these households, increases in output and income alone may not adequately address the specific nutritional needs of the population. To address these limitations, it is essential to design and implement robust institutional mechanisms. These mechanisms should prioritize inclusive growth in agriculture by integrating nutrition objectives and empowering women farmers. By fostering partnerships, creating capacity-building programs, and ensuring nutritional literacy at the grassroots level, these structures will help strengthen the vital linkages between agriculture and nutrition.

Rice-based Agri-Nutri Model for Enhancing Gender Equality and Nutritional Security

The Rice-based Agri-Nutri Model for Enhancing Gender Equality and Nutritional Security emphasizes the integration of gender-sensitive strategies within rice farming systems to enhance both productivity & nutritional outcomes. Women play an important role in rice agriculture; however, they frequently encounter gender-specific challenges, including restricted access to land, inputs, technology, education, & decision-making authority, which contribute to a productivity disparity compared to their male counterparts. Addressing these disparities through gender-responsive interventions—such as improving women's access to resources, providing technical training, and establishing supportive institutional frameworks—can substantially increase rice yields and household incomes while enhancing dietary diversity and nutritional security. Furthermore, empowering women within rice-based food systems not only fosters equality but also strengthens the entire agricultural value chain by diversifying production towards nutrient-rich crops and livestock, thereby mitigating malnutrition and hidden hunger.

The model emphasizes holistic strategies including social and technical innovations tailored to women's needs, policy reforms, and capacity building for women farmers. Such an approach transforms rice agro-systems into inclusive, sustainable, and nutrition-sensitive enterprises, advancing India's goals for food security, gender equality, and improved public health, especially in rural communities where rice is a staple crop. This model represents a critical pathway to addressing both agricultural productivity and nutrition challenges in a gender-equitable manner. The Rice-based Agri-Nutri Model for Enhancing Gender Equality and Nutritional Security incorporates gender-sensitive practices into rice farming to improve both productivity and nutritional outcomes. Women play a crucial role in rice cultivation but often encounter barriers such as limited access to land, inputs, technology, and decision-making power, resulting in lower productivity compared to men. By providing women with greater access to resources, technical training, and supportive institutions, the model aims to increase rice yields and household income while enhancing dietary diversity and nutritional security. This approach promotes the diversification of production towards nutrient-rich crops and livestock, addressing malnutrition and hidden hunger. It also involves policy reforms, capacity building, and gender-responsive innovations tailored to women's needs. By empowering women within rice-based agri-food systems, this model fosters equity, sustainability, and improved public health, particularly in rural communities where rice is a staple. This comprehensive strategy represents a critical pathway toward achieving food security, gender equality, and nutritional well-

being in India. It provides women farmers with opportunities to expand beyond traditional farming by engaging in livestock, fisheries, and kitchen gardening, thereby reducing their reliance on agriculture, which is often vulnerable to extreme weather events.

Involving youth in rice-based agri-food systems is crucial, especially as unemployment among young people is expected to worsen. South Asia will have the largest youth labor force globally by 2040, making youth engagement in agriculture essential for future economic stability (IRRI, 2023). The Gender Sensitive Agri-Nutri (G-SAN) Model was developed and validated through an innovative extension approach consisting of three primary stages: sensitization, skill development, and convergence. Acknowledging the complex relationship between agriculture and household nutrition, this model positions women as central stakeholders, utilizing agriculture as an effective means to enhance both nutrition and income. The G-SAN Model advocates for a gender-sensitive agri-nutri farming system that incorporates nutrition-enriched crops into the dietary habits of farming families. It promotes the cultivation of vegetables, fruits, and pulses on farms and in kitchen gardens, with the active participation and leadership of women farmers. The primary components of the model encompass the nutri-farming system, which emphasizes the cultivation of nutrient-rich crops; agri-nutri education aimed at increasing awareness of nutrition and sustainable agriculture; skill enhancement through training and capacity building; and institutional convergence that connects various stakeholders and institutions to effectively support farmers. This comprehensive approach not only improves farm productivity but also enhances dietary diversity and income generation for rural households. Overall, the G-SAN Model exhibits a significant positive impact on socio-technical and economic parameters, contributing substantially to women's empowerment and promoting sustainable agricultural and nutritional development in rural communities.

Gender Sensitive Approach for Bridging Gender Gap (Approach-I)

The 2018 Global Nutrition Report highlights that women bear a disproportionate share of malnutrition, with one in three women of reproductive age affected by anemia, and women showing higher rates of obesity compared to men. Additionally, millions of women are underweight (Malapit *et al.,* 2021). The Gender Sensitive Approach for Bridging the Gender Gap in Agriculture is structured around three integrated models: livelihood enhancement, nutritional security, and entrepreneurship promotion, each targeting different groups of women farmers based on farm size and roles. The Livelihood Enhancement Model focuses on small and marginal farm women engaged

in rice, pulse, and commercial vegetable cultivation. It has demonstrated substantial income generation, with group-based vegetable cultivation on 2 hectares producing a total income of ₹8, 01, 960, part of which was used for household consumption and the rest sold in the market. Rice production yielded high gross and net returns, with an average yield advantage of 62.5% from improved varieties, highlighting the economic potential of empowering women in small-scale farming.

The Nutritional Security Model targets medium-scale women farmers and focuses on cultivating high-protein rice, pulses, and commercial vegetables within Nutri-farms to enhance both nutrition and income. Key interventions include the introduction of bio-fortified paddy varieties enriched with 20–22 ppm zinc, which address critical nutritional needs of women and children. The promotion of home-based Nutri-farms supports diversified crop production and improved household diets. Over two hectares, vegetable farming generated ₹6, 55,515, with a significant portion allocated to household consumption while the remainder was sold in the market. Additionally, the cultivation of black gram (variety PU-31) resulted in a remarkable 63.08% yield increase compared to local varieties. Collectively, these interventions contribute to strengthening the economic status and dietary quality of farm families, fostering sustainable nutrition security.

The Entrepreneurship Promotion Model focuses on women from large-scale farms engaged in protected cultivation of high-value vegetables and value-added mushroom production. This model serves as a strategic pathway toward achieving self-reliance (*Atmanirbhar*) by empowering women through the development of agri-entrepreneurship skills, facilitating access to institutional resources, market linkages, and knowledge, thereby promoting sustainable livelihoods and economic inclusion. Women farmers were empowered through skills in mushroom cultivation, leveraging institutional and industry linkages for technology transfer, resource access, and market entry. Mushroom farming yielded an average of 651.4 kg, producing ₹1, 30, 280 in sales, with 30% output for household consumption and the remainder sold, enhancing women's economic independence. These interventions have enabled women to develop entrepreneurial and agri-business skills, fostering sustainability, and local economic growth.

Together, these models emphasize equity, empowerment, and entrepreneurship, facilitated by institutions like the Ananya Farmer Producer Company, creating a robust framework for closing the gender gap and enhancing women's roles in agriculture.

Nutri-SMART Village (NSV)

The concept of a 'Nutri-Smart Village' (NSV) is founded on a multi-sectoral strategy designed to address significant nutritional challenges, with a particular emphasis on combating malnutrition. In this initiative, Krishi Vigyan Kendras (KVKs), in collaboration with district-level partners such as Anganwadi workers, extension personnel, officials from the Women and Child Development Department, and primary health centres, have endeavoured to raise awareness and enhance literacy regarding the importance of balanced nutrition for overall health and development. KVKs have assumed a leadership role in meeting nutritional requirements, creating a supportive environment, sensitizing vulnerable groups, and promoting women's empowerment through balanced diets. They also contribute to building the capacity of villagers across various sectors of life. At the core of the NSV approach is the scientific principle, "You grow what you eat," which emphasizes community-led production and consumption of a variety of nutrient-dense foods. This local food system, primarily implemented through kitchen or rooftop gardens, offers direct nutritional supplementation to families while fostering self-reliance.

The model acknowledges that nutritional deficiencies within communities can often be addressed through minor, practical modifications to daily dietary plans. It underscores the importance of promoting and advocating for the traditional, balanced "Poshan Thali," a diet rooted in locally sourced and time-honoured recipes. This strategy is not only effective in alleviating nutrient deficiencies but also addresses broader social health issues and aids in the prevention of chronic lifestyle diseases by fostering healthier eating habits.

A key characteristic of the NSV model is the creation of mini-labs, which serve as innovative demonstration platforms to exhibit best practices in nutritional security. These mini-labs utilize locally available resources and emphasize motivation, nutritional literacy, and fostering positive attitude changes among villagers. By offering practical education and hands-on experience in sustainable food cultivation and dietary modifications, these facilities enable communities to make informed, health-oriented decisions. Overall, the NSV framework embodies a comprehensive, sustainable approach to enhancing both nutritional standards and the quality of life in rural areas.

Poshan Abhiyaan

Poshan Abhiyaan, launched in March 2018, is India’s main multi-ministerial initiative aimed at combating malnutrition and improving health among children, adolescent girls, pregnant women,

and lactating mothers. It targets significant reductions in stunting, undernutrition, anemia, low birth weight, and wasting in children by 2022, focusing on the critical first 1,000 days of life. The mission integrates various nutrition programs like ICDS, PMMVY, and the Mid-Day Meal Scheme, using technology tools such as ICDS-CAS and Poshan Tracker for real-time monitoring and improved service delivery by frontline Anganwadi workers. It also promotes community involvement through the Jan Andolan movement to encourage behavioral changes and collective action against malnutrition. This comprehensive approach aims to ensure better nutrition security and health outcomes across the country. The core components of the initiative encompass scheme convergence, technology-driven monitoring, behaviour change communication, capacity building through training, innovations such as nutri-gardens, incentives for frontline workers and states, and grievance redressal mechanisms. Additionally, the mission operates Nutrition Rehabilitation Centres for children suffering from severe malnutrition. Through these integrated efforts, Poshan Abhiyaan aims to establish a malnutrition-free India with enhanced maternal and child nutrition outcomes. Mission POSHAN 2.0 is a unified nutrition program launched by the Indian government to tackle malnutrition, focusing on children, adolescent girls, pregnant women, and lactating mothers. It highlights the critical first 1,000 days of life for ensuring optimal nutrition and long-lasting health, aiming to improve nutritional content, delivery, and outcomes through integrated efforts and enhanced service mechanisms. The mission engages in a large-scale mass movement known as Jan Andolan, which encourages community participation and stakeholder collaboration to foster sustained behaviour change towards improved nutrition.

Mission POSHAN 2.0 is anchored by a multi-sectoral convergence framework led by the National Council on India's Nutrition Challenges under NITI Aayog. This council ensures policy coordination and conducts quarterly reviews involving multiple ministries and departments. The mission heavily relies on technology, utilizing platforms like ICDS-Common Application Software (ICDS-CAS) and the Poshan Tracker for real-time monitoring and efficient service delivery by frontline workers such as Anganwadi workers. Funding mainly comes from the central government, with support from state governments and international organizations like UNICEF and the World Bank. POSHAN 2.0 streamlines several existing nutrition schemes—including the Supplementary Nutrition Programme, Anganwadi Services, and the Scheme for Adolescent Girls—to improve efficiency and impact. It focuses on raising nutrition awareness, encouraging healthy diets, and addressing nutritional deficiencies through targeted strategies. Regular monitoring, capacity

building, and community outreach underpin the mission's efforts to ensure accountability and maximize effectiveness, with the ultimate goal of creating a malnutrition-free India through sustainable health and wellness practices.

Nutri-Smart Village Programme for Strengthening Poshan Abhiyan

India is confronted with a significant malnutrition issue, as evidenced by its ranking of 101st out of 116 countries on the 2021 Global Hunger Index, which evaluates undernourishment, child stunting, wasting, and mortality. Malnutrition accounts for 15% of the nation's disease burden. Data from the National Family Health Survey 2019-21, encompassing 22 states, indicates limited progress in reducing stunting, wasting, and the prevalence of underweight children (NFHS 2019-21b). Economically, each USD 1 invested in nutritional interventions in India generates USD 34.1 to 38.6 in public returns, significantly surpassing the global average (RISE, 2025). Child malnutrition imposes a cost of up to 4% of India's GDP and diminishes productivity by up to 8%, underscoring the urgent necessity for effective nutrition programs such as the Nutrition Smart Village initiative (Sardar *et al.,* 2024). The "Nutrition Smart Village" program is a new initiative launched to strengthen Poshan Abhiyan as part of India's 75th Independence anniversary celebration, Azadi Ka Amrit Mahotsav. It involves adopting and transforming 75 villages selected by the All India Coordinated Research Project (AICRP) centers and the Indian Council of Agricultural Research (ICAR)-Central Institute for Women in Agriculture (CIWA). The program focuses on promoting nutrition awareness, education, and behavioral change in rural areas, targeting farm women and school children. It incorporates traditional knowledge through local recipes to combat malnutrition and promotes nutrition-sensitive agriculture practices like homestead farming and nutri-gardens. The Nutri-Smart Village Programme for Strengthening Poshan Abhiyan is structured around three primary interventions: nutritional enhancement, livelihood improvement, and entrepreneurship development (Bhadauria *et al.,* 2025). The programme has a broad scope, covering 13 states and 23 districts, and is implemented in 75 villages and 75 schools, directly benefiting 2,250 households. Comprehensive awareness initiatives are highlighted by the organization of 1,061 campaigns. The programme's tangible impact is evidenced by the establishment of 3,821 nutri-gardens and 90 nutri-farms, which serve as practical models for enhancing nutrition and food security at the community level. The initiative is supported by a network of esteemed research and agricultural institutions located across various regions, ensuring effective implementation and coordination. It involves the cultivation of nutrient-rich crops, community nutrition education, such as food pyramids to guide

dietary choices, and the active involvement of women and school children in both garden management and health monitoring activities. These integrated activities exemplify a comprehensive approach, empowering rural communities to improve their nutritional status, develop sustainable livelihoods, and promote a culture of health awareness and entrepreneurship, all of which collectively advance the objectives of Poshan Abhiyan across India.

Shree Anna (Millet) Gram - A New Vista for Nutritional Security and Women Empowerment

Nutritional insecurity represents a significant global challenge, particularly for populations that depend heavily on cereal-based diets often deficient in essential micronutrients. In numerous semi-arid tropical and drought-prone regions of Asia and Africa, millets constitute the primary source of energy following cereals (Kheya *et al.,* 2023). As one of the oldest domesticated crops, millets have been cultivated for approximately 10,000 years. These grains are nutritionally superior, providing higher levels of essential amino acids, minerals, vitamins, dietary fiber, and antioxidants compared to conventional cereals (Nagaraja *et al.,* 2024). Reflecting their exceptional nutritional value and cultural significance, the Honorable Prime Minister of India has designated millets as "Shree Anna," meaning “the best among all food grains,” symbolizing their esteemed status and potential to address nutritional security.

Shree Anna encompasses nutrient-dense millets such as Bajra, Jowar, Ragi, Kodo, Sama, and other indigenous grains traditionally cultivated in India (Kumar *et al.,* 2024). These "Holy Grains" are receiving renewed attention from the Ministry of Agriculture and Farmers Welfare due to their exceptional nutritional value, minimal resource requirements, and climate resilience. Millets are well-suited to drought conditions, requiring 80-90% less water than staples such as rice and wheat, making them ideal for arid regions like Rajasthan and Maharashtra (Agarwal, 2024). Their inherent hardiness reduces the need for expensive fertilizers and pesticides, providing farmers, particularly smallholders, with higher profit margins through cost-effective, sustainable farming practices.

Nutritionally, Shree Anna is a highly beneficial grain, abundant in protein, iron, calcium, zinc, magnesium, and dietary fiber, with a low glycemic index that is advantageous for managing diabetes, heart disease, and obesity. These gluten-free grains also enhance digestion and gut health, effectively functioning as a functional food. From an environmental perspective, millets contribute to sustainable agriculture by reducing chemical usage, lowering carbon emissions, preventing soil

erosion, enhancing soil fertility, and preserving biodiversity, thereby playing a crucial role in climate-smart farming.

The mutual benefits for farmers and consumers enhance rural livelihoods, empower women-led millet enterprises, and increase India's export potential in global health markets. The government actively promotes millets through initiatives such as the declaration of 2023 as the International Year of Millets, integration into mid-day meal and public distribution systems, millet value chains, and financial schemes like the National Food Security Mission. Awareness campaigns, helplines, and digital outreach support farmers in cultivation, marketing, and training. With the growing urban demand for millet-based snacks, cereals, and health foods, millets have transitioned from traditional staples to highly sought-after superfoods in both domestic and international markets.

Millet cultivation capitalizes on women's indigenous knowledge and ecological expertise, establishing them as pivotal contributors to sustainable agriculture and climate adaptation. Government initiatives that promote millets—such as their integration with nutritional programs and the provision of financial and technical support—enhance women's access to quality seeds, agricultural inputs, and markets. Furthermore, women-led self-help groups (SHGs) and entrepreneurial ventures concentrate on value-added millet products, including cookies, biscuits, and snacks, thereby fostering local economic growth and raising nutrition awareness. Facilitating the empowerment of women through training, capacity building, and the development of market linkages enhances their financial literacy and entrepreneurial skills, thereby improving their decision-making capabilities within both households and communities. This millet-focused empowerment initiative not only elevates the socio-economic status of women but also promotes gender equality, supports rural livelihoods, and addresses malnutrition by integrating the production of nutritious food with women's leadership in agriculture. The promotion of millet-based food consumption among farm women and school children is intended to enhance family nutrition by utilizing the substantial nutritional benefits of millets. Efforts are also focused on alleviating the physical demands on women engaged in millet cultivation by implementing technologies that are designed to be more accessible to women, thereby simplifying labor-intensive tasks. Furthermore, the advancement of millet processing and value addition capitalizes on traditional knowledge, empowering women to innovate and engage in the development of marketable millet products. This initiative not only improves livelihoods but also preserves cultural heritage.

Biofortification

Biofortification, or biological fortification, involves developing food crops with enhanced nutritional value and improved bioavailability through modern biotechnology, conventional breeding, and agronomic practices. The United Nations Food and Agriculture Organization estimates that approximately 792.5 million individuals worldwide are affected by malnutrition, with 780 million residing in developing nations. (McGuire *et al.,* 2015). Additionally, around two billion people experience "hidden hunger," a deficiency of essential micronutrients despite adequate calorie intake and increased food production (Hodge, 2016). Alongside these issues, overnutrition is also becoming a growing global concern. Biofortification offers a promising solution to address micronutrient deficiencies and improve overall nutritional security.

Biofortification of essential micronutrients in crops is accomplished through three primary approaches: transgenic (biotechnology), conventional breeding, and agronomic methods (Saltzman *et al.,* 2013). These methods have been applied to key staple crops such as rice, wheat, maize, sorghum, and legumes. Transgenic approaches are extensively utilized, particularly in cases where genetic diversity is limited, such as in oilseeds, while conventional breeding is more effectively employed when genetic diversity is present. Certain crops, including cassava and banana, have been biofortified using both transgenic and breeding methods. Transgenic techniques provide advantages by facilitating the use of critical genes, such as phytoene synthase and ferritin, across multiple crops to enhance nutrient levels efficiently (Schmidt *et al.,* 2015). Transgenic crops with higher micronutrient content have the potential to alleviate micronutrient malnutrition among consumers, particularly in low-income populations in developing countries (Hirschi *et al.,* 2009).

Evidence from agricultural fields demonstrates that biofortified crops frequently yield significantly higher outputs for farmers compared to non-biofortified varieties (Diressie *et al.,* 2019). In Rwanda, for instance, farmers cultivating iron-rich beans experienced a 16–23% increase in yields, which enhanced the crop's market value by 14% and augmented overall income by nearly 4% (Saltzman *et al.,* 2017). These crops are climate-smart, exhibiting tolerance to heat and drought, and require fewer inputs such as water, rendering them essential for mitigating the impacts of climate change. The rising levels of carbon dioxide pose a threat to reduce iron, zinc, and protein content in food crops by 3–17%, thereby risking widespread malnutrition. Biofortified maize enriched with Vitamin A is less susceptible to aflatoxin contamination, thereby enhancing nutritional safety. Furthermore,

Quality Protein Maize (QPM), developed through traditional breeding methods, improves grain macronutrient quality and is preferred in school feeding programs due to its sweeter taste (Karandikar *et al.,* 2018). Biofortified beans cook more rapidly, reducing the use of fuel wood and labor for women, thus benefiting both family health and the environment.

Several interconnected components are essential for the successful mainstreaming of these crops. Primarily, biofortified varieties must offer high yields to ensure that farmers are motivated to adopt them without compromising productivity. Enhanced yields render these crops competitive with conventional staples and contribute to food security on a broader scale. Nutritional biofortification is further enhanced when supported by robust quality seed production systems. Reliable access to quality seeds is fundamental for expanding cultivation. Additionally, biofortified crops present a price advantage for both farmers and consumers, as they often require similar or lower input costs compared to traditional varieties while offering higher nutritional benefits, thereby providing greater value for money.

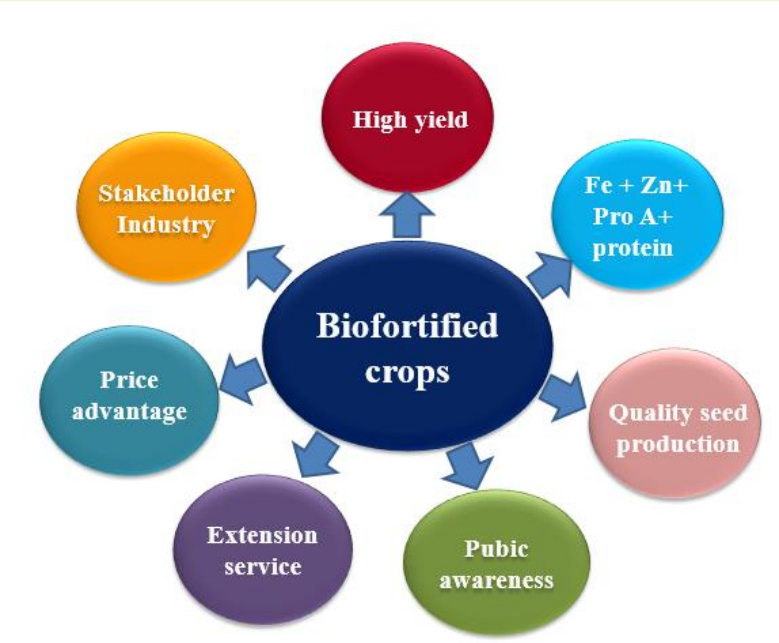

Fig. 2. Mainstreaming Biofortified Crops

The extension service network is instrumental in educating farmers on optimal agronomic practices, the health benefits of biofortified crops, and effective methods for integrating these crops into existing farming systems. Efficient extension services ensure that the necessary knowledge and tools for adoption are accessible to small and marginal farmers. Industry stakeholders play a crucial role

in establishing robust value chains, facilitating post-harvest processing, packaging, distribution, and marketing, thereby enhancing the availability and appeal of biofortified products to consumers. Public awareness campaigns are essential in informing communities about the benefits of biofortified foods, fostering widespread demand and increased consumption, which in turn amplifies their nutritional impact.

Way forward

Achieving nutrition security and gender equality necessitates a comprehensive, forward-thinking strategy that involves multiple sectors and stakeholders. Central to this approach is the sensitization and mobilization of women farmers at the community level, which is essential for expanding nutrition knowledge and ensuring healthy households. Empowering women with information and practical skills enables them to make healthier choices for their families. Strengthening public-private partnerships is also crucial in designing and implementing nutrition-smart agricultural interventions. This ensures that vulnerable groups, particularly rural women and school children, benefit from coordinated efforts that combine governmental and private expertise. Regular skill enhancement, delivered through targeted capacity-building programs, prepares communities to adopt and practice nutrition-enriching technologies, thereby enhancing both productivity and the nutritional profile of household diets. In addition to technical training, cultivating entrepreneurial skills among women can create new opportunities for income generation, drive innovation, and promote the production and sale of nutritious foods, thereby further empowering women both economically and socially. Promoting dietary diversity remains fundamental in addressing malnutrition and nutritional insecurity at both the household and community levels, ensuring a comprehensive approach that extends beyond staple-based diets. The establishment of robust monitoring and coordination units at both block and district levels is crucial for tracking progress, identifying gaps, and providing timely support to ensure programs achieve their intended outcomes. Finally, targeted policy advocacy and strategic interventions must be developed and implemented to reach the most vulnerable and underserved populations. This includes devising approaches that address unique local challenges, support sustainable progress, and advance the nation towards the Sustainable Development Goals of zero hunger and gender equality.

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Addressing Horticultural Crops for Food and Nutrition Security to Combat Global Hunger: The Indian Context

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Abstract

Among the biggest and most important issues of the twenty-first century is still world hunger, and India is essential to solving this problem. This chapter critically examines India's food and nutrition security status in light of the Global Hunger Index (GHI), identifying underlying causes of undernutrition, food distribution inefficiencies, and regional disparities. For instance, India received a "serious" score in the 2024 Global Hunger Index, placing it 105th out of 125 nations, underscoring the ongoing problems with child health and inadequate nutrition in spite of economic expansion. It discusses the evolution of public policies such as the Public Distribution System (PDS), Integrated Child Development Services (ICDS), and POSHAN Abhiyaan, analyzing their effectiveness and challenges. Furthermore, it highlights the role of agricultural innovations, technological advancements, and nutrition-sensitive interventions in reshaping India's food systems. The chapter also outlines key policy recommendations, such as promoting bio fortification, strengthening community-based monitoring, and enabling women-led nutrition strategies. With a multidimensional approach integrating agriculture, health, and social protection, India can emerge as a global leader in achieving Sustainable Development Goal 2 – Zero Hunger. Horticultural crops not only play a vital role in ensuring nutritional security and sustainable agricultural growth but also open avenues for empowering rural women through inclusive participation. Crops like Moringa, Mango, Potato, Turmeric, and Cucumber offer immense economic and ecological benefits while requiring labour-intensive yet skill-oriented practices, making them ideal for women's involvement.

Their cultivation fosters income generation, improved household nutrition, and social upliftment, thereby contributing to gender equity and sustainable development goals.

Keywords: *Biofortification, Climate-smart agriculture, Food security, Global Hunger Index, Horticultural crops, India, Nutrition security, POSHAN Abhiyaan, Public health policy.*

1. Introduction

Over the years, India, a country of almost 1.4 billion people, has achieved significant strides in agricultural growth and food production. Notwithstanding these successes, food insecurity and under nutrition are still major problems in the country. India is ranked **105th** out of 125 nations and a score of **27.3** in the Global Hunger Index (GHI, 2024) India has a level of hunger that is ***serious*****.** With severe levels of hunger caused by high rates of stunting (35.5%), child wasting (18.7%) and population undernourished (13.7%) (GHI, 2024). Food security, or the availability of enough food both financially and physically, and nutrition security, or the availability of food that satisfies dietary requirements for an active and healthy life, must be prioritised in order to address this issue (FAO, 2024). The interplay between hunger, poverty, inequality, and agricultural resilience is central to this discourse, especially in a country marked by stark regional and socio-economic disparities (UNICEF, 2024). Food and nutrition security are foundational to human health, economic development, and social stability. According to the Food and Agriculture Organization (FAO), food security exists when "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." Nutrition security, an extension of this concept, emphasizes not only the availability of food but also its quality, nutrient content, and biological utilization. A multifaceted statistical instrument that rates nations according to the degree of hunger is the Global Hunger Index (GHI). Undernourishment, stunting, wasting, and death are its four main indications. Concerns have been expressed about India's performance on the GHI in recent years. Hunger is a consequence of more serious systemic problems, such as poverty, inequality, bad governance, climate change, and insufficient public health systems. It is not just about a lack of food. Thus, ensuring food and nutrition security in India is not only a moral imperative but a strategic one that aligns with the United Nations Sustainable Development Goals (SDG 2 – Zero Hunger). This chapter aims to explore India's current food and nutrition landscape, assess the challenges behind its GHI ranking,

and evaluate key policies, technological innovations, and community-driven strategies that can help mitigate hunger in a sustainable and inclusive manner.

2. Understanding the Global Hunger Index (GHI)

Food security, as defined by the Food and Agriculture Organization (FAO), is "a condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food" (FAO, 2006). However, the concept has evolved beyond calorie sufficiency to encompass nutrition security, which focuses on balanced intake of macro and micronutrients essential for growth, development, and disease prevention (IFPRI, 2022). Policy discussions continue to revolve around the four foundations of food security: stability, utilisation, access, and availability. The advancement of universal nutrition security in India is still hampered by issues such as poverty, gender inequality, regional imbalances, and a lack of dietary diversity (Swaminathan & Bhavani, 2013). Despite efforts to connect the food, health, and sanitation sectors through programs like POSHAN Abhiyaan, there are still large gaps in monitoring and delivery (MoWCD, 2023). First introduced in 2006, the GHI highlights successes and failures in hunger reduction and provides insights into where urgent action is needed.

2.1 India's Performance on the GHI

India has shown only gradual progress in reducing hunger. In 2024, India was ranked 105th out of 125 countries, with a score of 27.3, placing it in the *"serious"* hunger category. Notably:

- Under nourishment affects 13.7% of the population.
- Child Wasting is alarmingly high at 18.7%, one of the worst globally.
- Child Stunting stands at 35.5%.
- Child Mortality has decreased but still contributes to the index.

These figures suggest that while India has made improvements in mortality reduction, acute and chronic under nutrition among children remain a significant issue, likely driven by factors such as poor maternal health, inadequate breastfeeding, poverty, and low dietary diversity.

3. Nutrition Security in India

While food security addresses the quantity of food, nutrition security focuses on the quality, ensuring adequate intake of essential nutrients. In India, the paradox of "hidden hunger"—micronutrient deficiencies amidst adequate calorie intake—is a growing concern. Despite significant agricultural

achievements, large segments of the population, especially women and children, remain undernourished or malnourished (FAO *et al.,* 2023).

3.1 Malnutrition in India: The Triple Burden

Malnutrition is a threefold burden in India:

- Under nutrition (underweight, stunting, and wasting)
- Deficits in certain micronutrients, such as iron, iodine, and vitamin A
- Obesity and overeating, particularly in urban areas.

According to NFHS-5 (2021):

- 35.5% of children under 5 are stunted (low height-for-age)
- 19.3% are wasted (low weight-for-height)
- 32.1% are underweight
- 57% of women (15–49 years) are anaemic
- Childhood obesity is on the rise in metro cities

These figures reflect inadequate maternal nutrition, poor infant feeding practices, and insufficient dietary diversity (IIPS & ICF, 2021).

3.2 Nutrition Challenges in Women and Children

- Maternal under nutrition increases risks of low birth weight and child malnutrition.
- Early marriages and frequent pregnancies among adolescent girls worsen the problem.
- Exclusive breastfeeding for the first 6 months remains suboptimal.
- In rural and tribal areas, access to protein-rich and fortified foods is minimal.

4. Horticultural Crops for mitigating hunger index: Empowering Women & Advancing Sustainable Goals

4.1. Moringa (*M. oleifera*)

Economic & Nutritional Importance: Moringa is nutrient-dense—rich in vitamins A, C, iron, and protein—and thrives in arid regions, making it ideal for agroforestry and year-round production. Nutrient-rich (leaves high in vitamins A, C, iron), drought-resistant, fast-growing, and value-added through powder, oil, tea, soap (Rockwood et al., 2013; Babayeju et al., 2014).

Nutritional & Sustainability Goals: By improving micronutrient content in diets and promoting soil conservation, moringa fosters both health and ecological resilience (Ramachandran *et al.,* 2011).

Women's Involvement and Advancement: Women often lead in processing moringa into powders and oils. Its low capital requirement allows them to engage in small-scale enterprises, boosting household income and autonomy. The cultivation and production of this crop helps in enhancing household incomes, provides micronutrients for women and children, supports agroforestry, and adds crop resilience (Rahim, 2017). It has been found that the FAO-led Ethiopian project empowered women to process and market moringa products (powder, soap), earning ~$3.8/week post-training (FAO Ethiopia, 2024).

Women's Role in Cultivation & Processing

- In Mucherla village (Telangana), tribal women formed a Joint Liability Group and, with ICRISAT support, established a moringa powder processing unit. They undertake leaf collection, drying, powdering, and packaging—transforming moringa from a subsistence crop to a small enterprise.
- Worldwide, women's moringa cooperatives serve as micro-entrepreneurs, capitalizing on natural medicine and cosmetics markets.
- Women gain skills in processing, business logistics, and nutrition science, increasing self-confidence and leadership. Moringa-based incomes allow women to invest in education and health, improving household well-being.

4.2. Mango (*Mangifera indica)*

Economic & Nutritional Importance: From numerous viewpoints, Mango fruit is crucial to the global economy and security of food. Economic mango production's financial success or failure, however, is mostly determined by regional weather and climatic variations. Since the seed of the mango is being identified as an organic waste with a significant amount of bioactive chemicals (phenolic compounds, carotenoids, vitamin C, and dietary fiber) that enhance the health of humans, it has attracted particular scientific attention (Torres-León *et al.,* 2016). Mango contributes significantly to India's horticultural sector and exports, with a high benefit–cost ratio (Pandey *et al.,* 2025). Mango is rich in vitamin A, C, β-carotene, fiber, and antioxidants, contributing to a healthy diet (Ghosh *et al.,* 2023; ScienceDirect, 2023). Consumption of mango has been associated with improved diet quality among women of reproductive age (Ghosh *et al.,* 2023).

Nutritional & Sustainability Goals: Mango peel and seed contain valuable bioactive compounds that reduce agro-industrial waste and promote food sustainability (Food Reviews International, 2021). Processing innovations like solar drying contribute to sustainable livelihoods (Gurjar *et al.,* 2018). The mango value chain supports Sustainable Development Goals (SDGs), especially zero hunger and gender equality (MDPI Sustainability, 2022; ScienceDirect, 2023).

Women's Involvement in Processing

- In Malihabad, Uttar Pradesh, sixty rural women from small farms trained in solar dehydration and improved peeling techniques produced dried mango slices (*Khattai*).
- These innovations led to a ~50% income increase and significant labour savings, demonstrating how women's engagement in value addition boosts nutrition and income.

Women's Role in Cultivation & Processing

- In Jharkhand, tribal women developed profitable mango orchards, gaining financial independence and social empowerment (Times of India, 2025).
- In Odisha, women-led FPOs transitioned from local to global markets by exporting mangoes (Times of India, 2025).
- Women in Uttar Pradesh participated in mango processing (solar dehydration), leading to income growth and entrepreneurship (Gurjar *et al.,* 2018). Empowerment through mango cultivation also leads to improved nutritional outcomes in households (Springer Food Security, 2019).

4.3. Potato (*Solanum tuberosum*)

Economic & Sustainable Importance: Potato offers quick yields and high returns per hectare, generating significant employment and supporting allied sectors (fertilizer, cold storage, transport).

Nutritional & Sustainability Goals: Potato is a low-cost, versatile staple rich in vitamins, minerals, and fiber. Biofortified varieties and inclusion in diversified systems enhance household food and nutritional security.

Women's Involvement

- In Bihar and Meghalaya, women-led Producer Organizations and training programs have increased market access, transparency, and earnings for female farmers.

- Women gained technical agronomic knowledge, business negotiation skills, and confidence to make independent choices.
- Earnings allowed investments in home improvements (toilet, LPG, healthcare, child's education).

Women's Role in Cultivation & Marketing

- In Bihar, 22 women farmers adopted zero-tillage technology (supported by Jeevika and CIP) to increase yield by 10–15%. They coordinate planting and irrigation, then share their successes to drive adoption.
- In Shopian, Kashmir, women's producer groups (via JKRLM) received training for the seed-to-market value chain, including packaging—enhancing financial independence.
- In West Bengal, TechnoServe WARDA empowered ~10,000 women to form Producer Organizations, learn best practices, and leverage direct marketing—helping Renu Devi sell 13 tonnes of potatoes transparently.

4.4. Cucumber *(Cucumis sativus*)

Economic & Sustainable Importance: Cucumber is a high-demand vegetable, easily cultivated in protected or open-field systems. When enhanced with moringa leaf extract (MLE), yields and quality improve under sustainable regimes. This crop is well known as a High-value vegetable crop; moringa leaf extract (MLE) is used as a bio-stimulant to enhance growth and yield (Kakbra, 2024).

Women's Involvement: Women often manage kitchen gardens and supplement income by selling cucumbers locally, especially when employing low-cost inputs like MLE. In community gardens, women utilize MLE treatments to increase production, contributing to both nutrition and income.

Nutritional & Sustainability Goals: Promoting cucumber supports household consumption of hydrating, vitamin-rich produce. MLE use reduces chemical fertilizer dependence, aligning with eco-friendly cultivation as well as chemical-reducing practices, and empowers women with low-cost inputs.

Women's Role in Cultivation and Production

- In homegardens (e.g., Nainital, Kumaun Himalaya), women perform nearly all steps of vegetable production—from nursery to selling.

- Experiments with moringa leaf extract (MLE) as a bio-stimulant in greenhouses improve yield and quality sustainably.
- Women applying MLE gain knowledge in organic cultivation, potentially branding and selling high-value produce.
- Kitchen gardens supply vegetable diversity and provide income more reliably.

4.5. Papaya (*Carica papaya*)

Economic & Sustainable Importance: Papaya is a high-value perennial crop, with vitamin A and C-rich fruits sold fresh or processed. Indian-developed hybrid varieties (e.g., 'Arka Prabhat') enhance productivity and resilience (IIHR, 2025).

Women's Involvement: Women often manage papaya in kitchen gardens or cooperatives, contributing to both income and nutrition education within households. Papaya fits well in women-led kitchen gardens and cooperatives, providing income and household nutrition.

Nutritional & Sustainability Goals: Papaya consumption supports dietary diversification and micronutrient intake. Agroforestry inclusion enhances biodiversity and reduces soil erosion. This crop also offers climate-resilient produce, diversifies agroforestry systems, and improves women's decision-making in crop choice.

Women's Role in Cultivation and Production

- Papaya is frequently grown by women in kitchen gardens or small farms; they handle planting, fruit thinning, and post-harvest handling.
- Women's cooperatives help in selling fresh fruits or processing into products like jam or juice—capitalizing on hybrid varieties (e.g., 'Arka Prabhat').
- Managing papaya production empowers women to learn horticulture and market management.
- Earnings are reinvested into households, improving nutrition and livelihood.

Table 1: Tabular representation of Horticultural Crops and roles of Women in Horticulture leading to their Nutritional, economic, and Sustainable development

Horticultural crops	**Women's involvement**	**Nutritional**	**Economical**	**Sustainable**
Moringa	Processing and value-added products.	Moringa powder is micronutrient-rich (iron, vitamins A & C), directly improving maternal and child health.	Value-addition supports small-scale women-led enterprises with low entry costs.	Drought-resistant, multi-purpose (leaves, seed oil, water purification), and easily integrated into agroforestry systems.
Mango	From cultivation to FPO export, dehydration, sorting, packaging—leading income gains and enhanced decision-making power	Rich in vitamins A, C, β-carotene, fiber, antioxidants; improves diet quality among key female populations	High profitability (BCR > 2), export opportunities, up to €108M pulp export from Tamil Nadu & Andhra	Agroforestry crop; valorizes waste (peel & seed bioactive compounds); reduces processing waste
Potato	Adopting tech, forming producer groups	Potatoes provide energy, fiber, and B-vitamins; biofortification adds micronutrient value.	Quick returns, integration into cold chains, and value addition improve incomes.	Zero tillage conserves water and soil; producer groups support market access.
Cucumber	Home cultivation with organic methods Fresh vegetables Local sales Reduced	Promotes access to vitamin-rich vegetables.	Sales from surplus increase household earnings.	Reduced chemical inputs foster eco-friendly farming.

	chemical input			
Papaya	Garden management and cooperative selling Vitamins A & C Perennial income Biodiverse perennial systems	Papaya provides vitamin A & C, fiber, and Digestive enzymes.	High-value crop with potential in local and Processed fruit markets.	Perennial system builds Biodiversity and soil health.

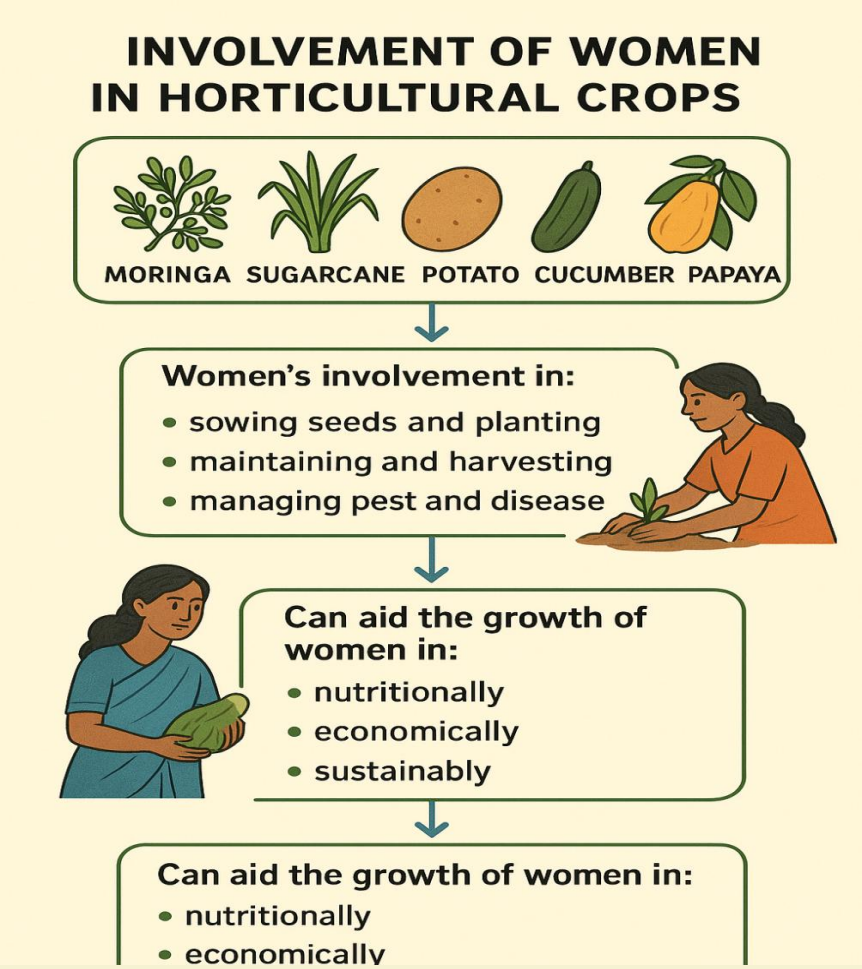

Fig.1. Flowchart showcasing involvement of women in various horticultural crops leading to their production, cultivation, and growth

5. Key Challenges Hindering Food & Nutrition Security in India

Despite various interventions, India continues to face significant barriers to achieving universal food and nutrition security. These challenges are multidimensional—ranging from economic disparities and systemic inefficiencies to cultural and climatic factors (FAO *et al.,* 2023; NFHS-5, 2021).

5.1 Poverty and Economic Inequality

Hunger is still primarily caused by poverty. More over 10% of Indians, according to the World Bank (2022), are below the global poverty level. The poorest households often lack access to diverse foods and rely heavily on calorie-dense but nutrient-poor diets. Economic inequality also widens the nutrition gap—urban middle classes have access to fortified and processed foods, while marginalized communities struggle with basic subsistence.

5.2 Climate Change and Environmental Stress

India is highly vulnerable to climate variability. Increasing incidents of droughts, floods, unseasonal rains, and heat waves negatively impact agricultural productivity and food availability. Studies suggest that by 2050, climate change could reduce India's wheat yield by 6–23% (World Bank, 2021). Climate-induced migration, water scarcity, and crop failures exacerbate hunger in ecologically fragile areas like Bundelkhand and Vidarbha.

5.3 Post-Harvest Losses and Food Wastage

India loses 30–40% of fruits and vegetables post-harvest due to inadequate storage, transportation, and market infrastructure (NITI Aayog, 2021). These losses translate into reduced food availability and economic losses for farmers. Simultaneously, urban food waste, particularly in restaurants and supermarkets, further adds to the problem of resource mismanagement.

5.4 Gender Inequality and Social Exclusion

Women and girls are disproportionately affected by food insecurity. Often, women eat last and least in Indian households. Cultural norms, gendered caregiving roles, and limited access to land and income sources hinder women's nutritional autonomy (IIPS & ICF, 2021). Marginalized communities such as Scheduled Tribes, Scheduled Castes, and migrant workers face social exclusion, leading to persistent nutritional deficits (MoWCD, 2023).

5.5 Weak Implementation and Leakages in Schemes

Although policies like NFSA, PDS, ICDS, and POSHAN Abhiyaan exist, leakages, corruption, and inefficiencies reduce their effectiveness. Exclusion errors in beneficiary lists, poor quality rations, and undertrained Anganwadi workers remain serious concerns (MoCAF&PD, 2023).

5.6 Lack of Dietary Diversity and Cultural Food Practices

Most Indian diets are cereal-centric (especially rice and wheat) with low intake of pulses, fruits, vegetables, and animal proteins. Lack of dietary education, regional food taboos, and poor market access further limit the adoption of balanced diets (FAO *et al.,* 2023).

6. Government Policies and Programs for Hunger Mitigation in India

In order to combat hunger and malnutrition, India has implemented a multi-sectoral strategy that includes social programs, targeted subsidies, food security legislation, and technology advancements. All four pillars of food security—availability, access, utilisation, and stability—are intended to be addressed by these measures (FAO *et al.,* 2023).

6.1 The 2013 National Food Security Act (NFSA)

Nearly 75% of rural and 50% of urban residents now have legal rights to subsidised food grains thanks to this historic law. Important clauses consist of:

- Each person receives 5 kg of wheat grain per month at discounted pricing (₹1-3 kg).
- Targeted Public Distribution System (TPDS) coverage
- Nutritional assistance provided by Anganwadi services to expectant mothers, nursing mothers, and children
- Mechanisms for addressing grievances

NFSA's reach is revolutionary, yet it also faces obstacles like supply chain inefficiencies, ration diversion, and identification problems.

6.2 Pradhan Mantri Garib Kalyan Anna Yojana (PMGKAY)

Over 800 million NFSA-eligible people receive free food grains (5 kg per person per month) through PMGKAY, which was started in response to the COVID-19 pandemic. From April 2020 until December 2022, it operated in several stages, greatly reducing the effects of hunger brought on by lockdown (PIB, 2022).

6.3 Mid-Day Meal Scheme (now PM POSHAN)

This scheme offers nutritious cooked meals to school children aged 6–14 years in government and aided schools. The revised PM POSHAN scheme includes:

- Diversified menus with local grains and vegetables
- Fortified rice rollout
- Tithi Bhojan (community participation)

It improves child nutrition, school attendance, and social equity (MoE, 2023).

6.4 Integrated Child Development Services (ICDS)

Since 1975, ICDS has been India's flagship early childhood care and nutrition scheme, providing:

- Supplemental diet
- Health examinations
- Referral services and immunizations. Preschool instruction that is not official ICDS, which is administered through Anganwadi Centres, is intended for children under six as well as expectant and nursing mothers (MoWCD, 2023).

6.5 POSHAN Abhiyaan (National Nutrition Mission)

Launched in 2018, POSHAN Abhiyaan integrates efforts across ministries to reduce stunting, anaemia, and undernutrition using a lifecycle approach. It emphasizes:

- Real-time monitoring through the JAN Andolan movement
- Focus on the First 1000 Days
- Community-level awareness and behavioral change (MoWCD, 2023)

6.6 Food Fortification Initiatives

India has scaled up food fortification through:

- Fortified rice under PDS, MDM, and ICDS
- Iodized salt, fortified wheat flour, and edible oil with vitamin A & D

These are promoted by the Food Fortification Resource Centre (FFRC) under FSSAI to combat hidden hunger (FSSAI, 2023).

7. Conclusion and Recommendations for the Way Forward

Large-scale food security and nutrition initiatives have helped India reduce hunger and malnutrition, but ongoing regional and socioeconomic inequalities necessitate a more inclusive, resilient, and integrated strategy. These strategic suggestions aim to enhance India's food and nutrition security and raise its Global Hunger Index (GHI) score, taking into account the shortcomings noted in the previous sections. India's efforts to eradicate malnutrition and food insecurity are at a critical juncture. By leveraging science, improving governance, empowering women, and promoting equity, India can substantially improve its GHI rank and ensure that "zero hunger" becomes a reality for all. A multi-stakeholder, inclusive, and sustainable approach is the key to achieving SDG 2: Zero Hunger by 2030.

7.1 Strengthening Nutritional Outcomes

Mainstream nutrition-sensitive agriculture: Promote crop diversification toward nutrient-rich staples (e.g., millets, pulses, biofortified crops) to combat hidden hunger and micronutrient deficiencies (FAO, 2023). Scale-up biofortified crop varieties through public-private partnerships and awareness campaigns to increase adoption among smallholders (HarvestPlus, 2023). Expand fortification of rice, salt, and edible oil in more states under PDS and ICDS while ensuring quality compliance through regular monitoring (FSSAI, 2023).

7.2 Targeted Policy Reforms and Governance

Shift from calorie-centric to nutrition-centric policies by integrating health, agriculture, and education efforts under convergent platforms like POSHAN Abhiyaan (MoWCD, 2023). Improve data systems at the local level to enable real-time tracking of hunger and undernutrition using digital dashboards like the POSHAN Tracker (NITI Aayog, 2021). Establish community-based monitoring of services at Anganwadi centres, midday meal kitchens, and ration shops to reduce leakages and inefficiencies (World Bank, 2022).

7.3 Enhancing Agricultural Resilience and Climate Adaptation

Promote climate-smart agriculture (CSA) with emphasis on water-efficient practices, integrated pest management, and resilient crop varieties (ICAR-NICRA, 2023). Strengthen farmer access to agro-advisories, insurance (PMFBY), and credit support to reduce vulnerability to shocks like droughts,

floods, and market volatility (MoA&FW, 2023). Invest in decentralized food storage and cold chain to minimize post-harvest losses and ensure food availability throughout the year (NABARD, 2022).

7.4 Empowering Communities and Women

Involve women in self-help groups (SHGs), kitchen gardening, and nutrition education to acknowledge and reinforce their important role in ensuring the food and nutrition security of households (UNICEF, 2022). To end the intergenerational pattern of undernutrition, educate teenage girls, expectant mothers, and nursing mothers about nutrition. (MoWCD, 2023).

7.5 Encouraging Technological and Social Innovations

Support AgriTech startups and digital platforms to deliver customized services, market linkages, and nutrition advisories to small and marginal farmers (NASSCOM, 2022). Encourage local innovations, such as community kitchens, millet-based nutrition programs, and participatory meal planning, especially in tribal and aspirational districts (NITI Aayog, 2021).

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Home Gardening as a Strategy for Food Insecurity: An Overview

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Abstract

Home gardening households have better access to micronutrient-dense fruits and vegetables, such as those high in iron and Vitamins A and C. Home gardens may have their roots in the prehistoric past, at a time when humans were hunters and gatherers disseminated the seeds of valuable fruit trees near their camp sites, either on purpose or by accident. Food insecurity continues to be a pressing challenge worldwide, affecting both rural and urban populations due to factors such as population growth, rising food prices, limited land resources, and climate change. Gardening at home has become a low-cost, sustainable approach to deal with food insecurity by ensuring frequent availability of secure, diverse, and healthy food. Home gardens, often managed in backyards, rooftops, or small plots near households, enable families to produce vegetables, fruits, herbs, and sometimes small livestock or fish. Beyond supplementing staple diets, they diversify food intake, contributing to improved micronutrient consumption and overall dietary quality. Additionally, home gardening reduces dependence on market-purchased food, lowering household expenditure and enhancing resilience against economic shocks. It also offers strategies to get revenue by selling excess produce, empowering women and underprivileged communities who are often primary caretakers of these gardens. Despite these benefits, challenges such as limited access to quality seeds, water scarcity, lack of technical knowledge, and urbanization pressures hinder the widespread adoption of home gardening. Policymakers, extension services, and community-based organizations play a crucial role in supporting households through training, resource provision, and awareness programs to maximize the potential of this practice. In conclusion, home gardening is not merely a subsistence activity but a multidimensional strategy that addresses food insecurity, enhances nutrition, reduces poverty, and fosters sustainable development. Strengthening and scaling up home

gardening initiatives, particularly in vulnerable communities, can play a vital role in attaining nutrition and food security in communities and households.

Keywords: Food insecurity, Home Gardening, Nutrition security, Sustainability, Urban Agriculture.

Introduction

A key reaction tactic during the epidemic was home gardening, which is the practice of growing fruits, vegetables, and herbs in tiny plots or pots around the house. It is a cost-effective and environmentally friendly way to increase access to wholesome, fresh food. Home gardening greatly enhances nutritional security by allowing families to produce a variety of meals high in vital vitamins, minerals and proteins (Galhena *et al.,* 2013). According to empirical research, home gardening households have better access to micronutrient-dense fruits and vegetables, such as those that are rich in vitamins A and C and iron etc. All these nutrients are essential in order to avoid malnourishment, particularly in vulnerable populations like pregnant women and children (Nwankwo *et al.,* 2022). Specifically, evidence suggests that home gardening plays a role in lowering vitamin A deficiency which is a critical public health problem in Nigeria. Additionally, home gardening makes households more resilient to supply chain disruptions and price fluctuations by lowering reliance on outside food sources—problems that were particularly noticeable during COVID-19 lockdowns (Tanimonure *et al.,* 2025). Through direct and indirect channels, home gardeners expand the food supply in home and produce financial and nutritional advantages. Through direct and indirect channels, home gardeners increase the availability of food in the home and produce financial and nutritional advantages. Additionally, compared to more affordable staples and, increasingly, inexpensive processed snack meals, in addition to being expensive in stores and marketplaces, many of the fruits and vegetables that are typically grown in home gardens are also high in micronutrients (Rammohan *et al.,* 2019). Despite not being the main source of household nutrition, home gardens' significant species diversity contributes significantly to the variety of household diets. (Kumar & Nair, 2004). For instance, almost 75% of home gardens in Nepal's wetter, middle-hill regions had between 21 and 50 different species per household (Gautam *et al.,*2006). Home gardens may have their roots in the prehistoric past, at a time when humans were hunters and gatherers disseminated the seeds of valuable fruit trees near their camp sites, either on purpose or by accident (Hutterer, 1984). According to Brownrigg's (1985) literature survey, the origins of these historic gardens may date back to the seventh millennium BC. They were affixed to palaces,

temples, homes of the aristocracy, and ordinary people, family gardens in the Near East have been documented from the third millennium BC in writings, paintings, and papyrus images. They were affixed to palaces, temples, homes of the aristocracy, and ordinary people. According to Ahmad et al. (1980), home garden revenue was 25.5% of total income prior to the rice harvest, also known as the *paceklik* or lean season. It then fell to 6.4% of total income during and right after the rice harvest.

Origin of word "Gardening"

1. Germanic Roots: The world's deepest roots are in Germanic languages. Old High German "Gard" and Old English "Geard" both meant "Enclosure" or "Fence".

2. Old North French: The English word "Garden" came from the Old North French "Gardin" and Old French "Jardin", which also referred to an enclosed green space.

Advantages of Home Garden

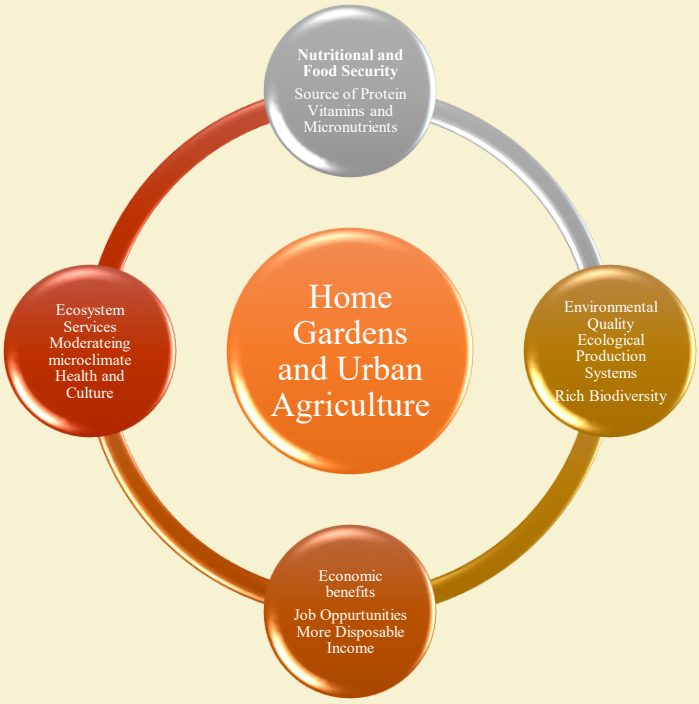

Fig. 1. Advantages of Home Gardens and Urban Agriculture

1. The social advantages of home gardening

- In both urban and rural areas, home gardens are maintained to provide convenient availability of fresh plant food sources.

- By improving the availability, accessibility, and consumption of food products, home gardens make a major positive social contribution by directly strengthening food security at the household level.
- On a regular basis, agricultural produce from home gardens greatly boosts a family's energy and nutritional intake.
- Home gardens offer low-cost access to nutrient-rich foods for low-income households that cannot afford expensive animal-based products to fulfill their nutritional needs.
- According to Marsh (1998), home gardens offer wholesome and fresh food for daily household endeavors.
- In addition to growing plants, integrating livestock and poultry operations in the home garden strengthens families' nutritional as well as food security because home-raised animals provide milk, eggs, and meat.
- Some home gardens go beyond plants, people grow mushrooms, tend beehives, and have small ponds stocked with freshwater fish to their gardens, increasing the family's access to proteins and other nutrients.

2. Enhancement of Health with Home Gardening

Nearly 80 percent of people in developing countries depend on medicinal herbs to improve their overall health and treat a range of diseases and conditions. Therefore, many individuals cultivate these plants at home for this purpose.

- Inadequate consumption of essential macro and micronutrients is one of the causes of negative health impacts in humans.
- Vitamin A deficiency is a significant health concern in many low-income nations, which can lead to severe health issues, particularly for expectant mothers and developing children (WHO 2009).
- Over 7 million mothers in Africa and Asia suffer from vitamin A deficiency, which accounts for 6-8% of child fatalities under five years old (West and Darnton-Hill, 2008).
- The production of food on a homestead initiative has been established in various nations where this issue is acute in order to promote and cure vitamin A deficiency and to enhance dietary quality by enabling a year-round supply of fruits and vegetables.
- During pregnancy, an iron deficit raises mortality by 20 percent (Stoltzfus *et al.,*2004).

- Furthermore, estimations indicate that around one-third of the world's population resides in nations with significant levels of zinc deficiency (Benoist *et al.,* 2007).
- Therefore, this micronutrient shortage might increase susceptibility to various infectious diseases and the likelihood of dying from conditions including malaria, pneumonia, and diarrhea (Black *et al.,* 2008).
- Home gardening projects are designed and carried out in various contexts as a means of addressing health problems brought on by hunger. Despite the possibility, nothing is done to recognize and optimize the many health benefits of home gardening.

3. The Economic Advantages of Home Gardening

- Home gardens have more financial advantages than only ensuring nutrition and food security as well as survival, particularly for households with limited resources (Trinh *et al.,* 2003; Laura *et al.,* 2012).
- For low-level income families with restricted availability of production inputs, the cost-effectiveness and reduced investment requirements of home food production are crucial.
- Home gardens that incorporate livestock production can yield as much revenue per unit area as those that grow field crops.
- Innovative technologies have been employed to efficiently utilize available space in areas where there is a shortage of land.
- Additionally, home gardens with animals reduce crop loss risk and give the household a source of income and assets.

4. The advantages of home gardening for the environment

- Significant ecological and environmental advantages can be obtained from home gardens.
- They serve as the main organization that develops and applies environmentally friendly methods for producing food while preserving natural resources and biodiversity.
- A diverse range of plant and animal species are typically found in home gardens.
- As a result, they provide intriguing examples for ethnobotanical research that has concentrated on assessing the actual or projected economic contribution to social development and the family and local economies (Kehlenbeck *et al.,* 2007).
- Home gardens can help conserve land and reduce soil erosion (Terra, 1954; Soemarwoto, 1987).

- Additional advantages of honey bee attraction include enhanced pollination and higher fruit set.
- The cycle of nutrients is another ecological benefit of home gardens (Gajaseni and Gajaseni, 1999; Kumar and Nair, 2004; Seneviratne *et al.,* 2010).
- There is a symbiotic link between plants and animals in home gardening.
- In order to reduce the need for artificial fertilizer, for instance, plant components are utilized as animal feed, and animal dung is mixed into compost to nourish plants.

5. Gardening at home to elevate women's status

- Women are essential to the production of food in many societies, although occasionally their value is slightly undervalued.
- Although their participation in home gardening is sometimes influenced by sociocultural conventions, they also actively participate in it (Moreno-Black *et al.,* 1996).
- Gardens were crucial in raising the wealth and social standing of women, but they had little effect on food consumption or nutrition.
- A few women rely on selling garden goods as their only source of income.
- Through home gardening, women have gained knowledge about plants and garden techniques that have increased their ability to manage their homes and environments.
- To keep the garden in good condition and assist in maintaining production costs down, labor is essential.
- Women manage the home and are therefore well-versed in a variety of domestic requirements.
- They can more readily and affordably provide basic needs for their families by participating in the industrial process (Krishnaveni *et al.,* 2023).
- Home gardens have greater socio-cultural and religious significance for women, even though they provide a good way for them to contribute to household survival, eminence, and character.

6. Enhancement of food security during COVID-19 through home gardening

- Lal et al. (2020) claim that the COVID-19 pandemic has increased urban food insecurity as a result of the food supply chain being interrupted, exacerbated the financial and physical

obstacles that limit access to food, and caused an enormous increase in food waste due to a lack of workers.

- Therefore, it is essential to implement more adaptable food systems, decrease food waste, and support regional food production.
- One of the most crucial strategies may be to increase food availability in households and communities through home gardening.
- Throughout and following the COVID-19 outbreak, home gardening can significantly improve food and nutritional security while reinforcing the provision of several ecosystem services (e.g., microclimate, plant biodiversity, and human health).

Features of Home Garden

According to Michelle and Hanstad (2004), home gardens have five distinguishing features:

- A home garden is situated close to the home.
- It has a wide variety of plants.
- Its production serves as a supplement to the family's income and consumption rather than as its primary source.
- It takes up small amounts of sp (Brownrigg, 1985).
- It is a system for producing products that the impoverished can readily participate in to some extent (Marsh, 1998).

Challenges of Home Garden

- One of the biggest obstacles is access to land, especially in crowded urban areas with limited space.
- The size of gardens is limited in rural areas by land fragmentation brought on by population growth.
- Furthermore, a lot of gardeners lack access to high-quality inputs like seeds, fertilizer, and the technical know-how required to maximize yields.
- Gardening is made more difficult by climate change, which shows up as unpredictable rainfall and rising temperatures (Nwankwo,2022).

Food Security

Food security is achieved when everyone, everywhere, has physical and financial access to enough wholesome food that satisfies their dietary requirements and tastes for an active and healthy life (World Food Summit, 1996).

Dimensions of Food Security

These dimensions are generally accepted and supported by reliable worldwide sources. (FAO,2006):

1. Availability – Consistent and sufficient supply of food.
2. Access – People must possess both financial and physical means to obtain food.
3. Utilization – Food must be safely and effectively used by the body, including adequate nutrition, water, and sanitation.
4. Stability – Access to food must be reliable over time, unaffected by shocks or seasonal fluctuations.

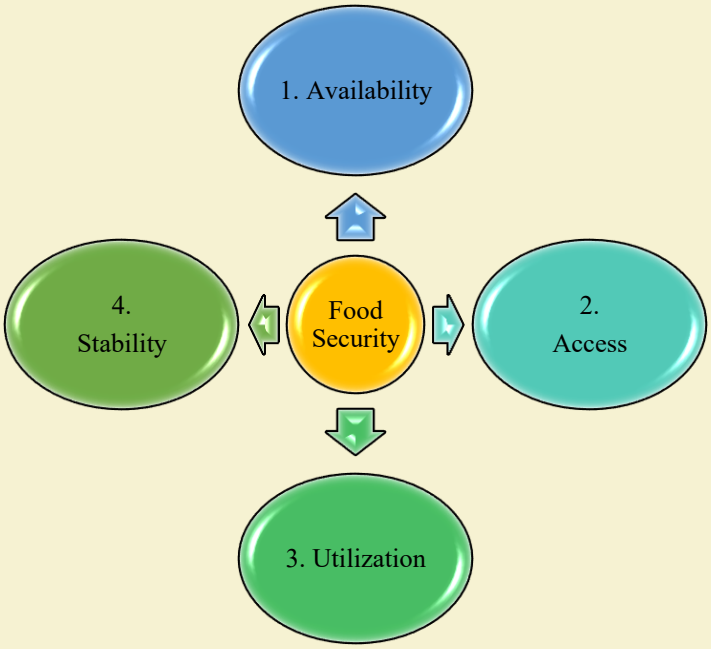

Fig. 2. Dimensions of Food Security

India remains extremely concerned about food security. India is home to the second-largest quantity of undernourished people in the world (195.9 million), despite being the world's second-largest producer of food (Suri,2020). Micronutrients can be found in abundance in fruits and vegetables grown in kitchen gardens, particularly in low-income households. Due to the large amount of space

in rural areas and the involvement of farm families in agriculture, establishing a kitchen garden is much easier (Landauer & Brazil,1990).

Role of Extension Services

To encourage sustainable gardening techniques like organic farming and integrated pest management, training and extension services must be expanded (Tanimonure, 2025). Agricultural extension ensures that knowledge-driven improvements reach the individuals in charge of food production by acting as a link between farming communities and scientific research. Continuous increases in yield from agriculture, sustainable resource management, and market accessibility—all of which rely on efficient extension services—are necessary to ensure food security. Extension programs increase food security by giving farmers market-driven farming techniques, post-harvest management competencies, and climate-smart agricultural practices (Khatri et. al., 2025).

Innovative ways to do home gardening

1. **Sustainable landscaping:** The design and planning of outdoor areas that incorporate ecological, environmental, social, and economic sustainability elements is known as sustainable landscaping. Water conservation, halting soil erosion and deterioration, minimizing air, soil, and water pollution, and lowering greenhouse gas emissions are some of these environmentally friendly measures (Lier,1998; Rehana et. al., 2023).

2. **Smart Soil Sensors:** A soil moisture sensor measures the volumetric amount of water present in the soil (Wobschall *et al.,* 2005). By inserting this sensor into the ground, the moisture content of the soil may be ascertained, and the water content condition is noted as a ratio. The difference in sensitivity is equal to the amount of water in the soil; the more water there is in the soil, the greater the conductivity, and thus, the lower the sensitivity.

3. **AI & Smart Lighting for Growth:** Smart indoor gardening systems use full-spectrum LED lights and grow-light technology optimized by smart soil monitoring. At events like the Chelsea Flower Show**,** winning designs showcased AI diagnostics**,** solar-powered irrigation**,** and laser imaging to help manage environmental stress and disease in gardens (Lane, M., 2025)

4. **AI & Biosensor Integration:** Biosensors embedded in soil can provide real-time health data for individual plants, feeding it back to your smartphone or computer— for disease

monitoring or early detection, which will support sustainable agriculture. Furthermore, it is essential for identifying disease-causing bacteria, detecting pesticides, herbicides, and fertilizers, detecting food adulteration, measuring soil conditions, detecting heavy metal ions, and detecting some illicit additives (Hazarika *et al.,*2022).

5. **Smart Irrigation Systems:** Controllers like Orbit B-Hyve**,** Rachio**,** and Rain Machine adapt watering schedules based on soil moisture, weather forecasts, and plant-specific needs. They often include remote control features via mobile apps, enabling you to adjust watering even when you're away (Orbit,2025).

Benefits of Innovative Home Gardening

i. **Efficiency & Sustainability:** Automating watering and care conserves resources, saves time, and reduces stress for the gardener.
ii. **Data-Driven Gardening:** Real-time monitoring helps tailor care to each plant's specific needs.
iii. **Accessibility:** These technologies make gardening easier for beginners, busy individuals, or those with physical limitations.
iv. **Future-Ready Design:** AI-enhanced features bring predictive insights, helping gardens adapt to changing weather and environmental conditions (Nymon, L., 2025).

A smart indoor gardening setup based on market segmentation

i. According to type: Wall and floor garden.
ii. According to Technology: Smart pest control, Smart sensing, self-watering and other technologies.
iii. According to end-use: Residential and Commercial.

Sub-segments:

i. According to floor garden: vertical and Container floor garden.
ii. According to wall garden: Vertical and pocket wall garden (The Buisness Research Company, 2025)

Food Insecurity: Food insecurity is a complicated issue that is impacted by social, cultural, political, and economic issues that have an immediate bearing on the production, distribution, accessibility, and use of food (Bathfield, 2012). Addressing these issues and achieving the Sustainable Development Goals (SDGs), which include eradicating hunger, have not proceeded as planned (FAO, 2023). For children, expectant mothers and nursing mothers, eating a variety of food

categories is essential for their cognitive and physical development (Bhutta *et al,* 2013). Therefore, as home gardens provide a range of herbs, fruits, vegetables, and grains that are high in essential nutrients, having access to home garden production can enhance household nutrition. Food insecurity, which includes both the financial and physical difficulty to obtain enough food, is defined as not having regular, adequate access to enough safe, nutritious food for a healthy and active life. It can be brought on by a shortage of resources and has detrimental effects, particularly on children, including stunting, wasting, hunger, and malnutrition.

Government and NGO Initiatives to Combat Food Insecurity

1. **National Nutrition Mission (NNM)/Poshan Abhiyan**

- Introduced by the Indian government in 2018 to combat undernourishment among children, teenage girls, expectant and nursing mothers.
- Encourages the establishment of "Poshan Vatikas" (Nutrition Gardens) in homes, schools, and Anganwadi centers.
- Increases community involvement and health and nutrition awareness.
- Increases community involvement and health and nutrition awareness.

2. **Poshan Maah (Nutrition Month)**

- Poshan Abhiyan is celebrated in the month of September.
- Promotion of kitchen gardens and home gardening is given particular attention.
- Encourages families and communities to embrace nutrient-dense gardening practices through campaigns, demonstrations, and training.

3. **Indian Council of Agricultural Research (ICAR)**

- Encourages agriculture that is attentive to nutrition through its extension and research departments.
- Crop-specific advice
- Nutrient management that is integrated.

- Bio-farming and organic agricultural methods.
- Creates garden models tailored to individual locations in various agro-climatic zones.

4. Krishi Vigyan Kendras (KVKs)

- Serve as ICAR's grassroots extension system.
- Give home gardeners seeds, planting supplies, instruction, and technical assistance.
- Showcase models of nutrition gardens in both urban and rural homes.
- Encourage the use of composting, biofertilizers, and water-saving methods.

5. NGOs and Civil Society organizations

- MSSRF (M.S. Swaminathan Research Foundation) is one example.
- Developed the first models of bio-diverse farming and nutrition-sensitive agriculture.
- Uses communal and family gardens to promote "Mahila Kisan Sashaktikaran," or the empowerment of women farmers.
- Focuses on combining women's empowerment, biodiversity, and local food expertise.
- Uses kitchen gardens to lessen hidden hunger in rural and tribal areas.

Conclusion

A tributary to the diversity and preservation of genetic resources in plants and ecology, home gardens are crucial in lowering vulnerability, ensuring food security, and improving ecological conditions, employment prospects, and social conditions for exceptional production. There are opportunities for home gardens in the areas of food availability and accessibility for community protection, marketable product creation, and gender participation (Khan et al, 2021). The food supply system has been upset by the COVID-19 epidemic, which has made undernourishment and malnourishment worse worldwide, but particularly in developing nations. Urban agriculture and home gardening are two methods of producing food in cities that can reduce food waste along the supply chain and build resilient food systems. Using compost and other organic amendments to restore the condition of urban soils is crucial for increasing human health, productivity, and nutritional quality as well as for guaranteeing safety.

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Enhancing livelihood opportunity of the farming community through market linkages in Mid-hills regions

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Abstract

The mid-hill regions of India, particularly Uttarakhand, remain heavily dependent on agriculture. The major agricultural constraints are small landholdings, limited irrigation, and market access. This study explores interventions aimed at enhancing livelihood opportunities for hill farming communities through improved market linkages. By introducing improved vegetable varieties, primary processing, and promoting collective marketing, alongside supporting livestock, beekeeping, and mushroom modules, demonstrated significant income gains and socio-economic resilience. The establishment of institutional and ICT-enabled market connections, including Farmer Producer Organizations (FPOs) and direct marketing models, has strengthened bargaining power, reduced transaction costs, and increased value addition. Case studies from selected villages illustrate the efficacy of context-specific interventions in diversifying income sources, empowering women, and fostering sustainable agricultural development. The findings underline the significance of robust market linkage mechanisms as a pathway for inclusive and resilient livelihoods in India's mid-hill regions.

Keywords: Collective marketing, Livelihood enhancement, Mid-hill regions, Rural entrepreneurship and Vegetable cultivation.

Introduction

Agriculture remains the primary livelihood source in India's mid-hill regions, such as those in Uttarakhand, where over 75% of the population depends on farming activities (Singh *et al.,* 2018). However, the sector is predominantly characterized by small and marginal holdings, subsistence-level production, and limited irrigation facilities. Enhancing livelihood opportunity

in such contexts refers to creating diversified and sustainable income-generating avenues for rural households through improved agricultural productivity, value addition, and access to remunerative markets (FAO, 2017; Lal et. al., 2021). The farming community encompasses all households engaged in crop cultivation, horticulture, livestock rearing, and allied activities, often under resource-constrained conditions. Market linkages are the institutional, infrastructural, and informational connections that enable producers to sell their goods efficiently, obtain fair prices, and integrate into value chains (Birthal *et al.,* 2005). The mid-hill regions are agro-ecological zones typically located between 1,000 and 2,000 meters above sea level, with specific climatic and topographical constraints but also potential for high-value agriculture, horticulture, and niche products.

In the mid-hills, livelihood enhancement depends heavily on the ability of farming communities to access reliable and profitable markets. Without functional market linkages, even increased production fails to translate into improved incomes due to post-harvest losses, exploitative intermediaries, and price volatility. Strengthening these linkages through Farmer Producer Organizations (FPOs), cooperatives, ICT-enabled platforms, and direct marketing can bridge the gap between small producers and high-value markets, ensuring better bargaining power, reduced transaction costs, and greater income stability. For instance, successful interventions in Uttarakhand's "Honey Villages" and "Poultry Villages" have demonstrated that collective marketing and value addition can double or even triple farm incomes (Sharma *et al.,* 2022). The significance of this topic is heightened in the present context of climate change, rural distress, and market volatility. Mid-hill farmers face additional challenges such as male out-migration, feminization of agriculture, and declining productivity due to labour shortages and land degradation (Gandhi & Jain, 2011). In such conditions, market-oriented interventions not only enhance incomes but also encourage sustainable resource use, women's economic empowerment, and local enterprise development. Furthermore, aligning production with market demand through real-time market intelligence can reduce wastage, increase competitiveness, and strengthen rural economies. Given the potential for niche, high-value products from mid-hill regions such as organic vegetables, honey, and specialty mushrooms there is an urgent need to develop robust market linkages as a pathway to inclusive and resilient livelihood enhancement.

Uttarakhand: Agriculture Scenario

Agriculture forms the backbone of Uttarakhand's economy, with more than 75% of its population dependent on it for livelihood. The sector is largely subsistence-oriented, characterized by mixed cropping systems and very limited irrigation coverage—only around 10% of the cultivable land has access to irrigation facilities. The predominant crops in the hill regions include rice, wheat, and maize, along with horticultural produce such as plum, peach, pear, and mango, and vegetable crops like potato, tomato, green pea, cauliflower, and capsicum. However, farmers face multiple challenges—technical constraints such as low productivity due to inadequate irrigation and agronomic practices, as well as economic barriers like poor market access, low bargaining power, and post-harvest losses. Such problems restrict the potential for surplus production and income enhancement, particularly in the mid- and high-hill zones where transportation and infrastructure constraints are more pronounced.

Within the agricultural sector, vegetable cultivation has emerged as a significant sub-sector with considerable potential for income generation. Production is chiefly concentrated in Dehradun, Nainital, and Tehri Garhwal districts, which together account for approximately 40% of the total area under vegetables in the state. Vegetables such as cabbage, capsicum, and peas offer higher returns per unit area compared to cereals, making them an attractive option for smallholders (Choudhary *et al.,* 2017). Notably, Uttarakhand stands out among Indian states for the prominent participation of women in agricultural activities, particularly in the hill regions, where male out-migration has led to a feminization of agriculture. Women are actively involved in all stages of vegetable cultivation (Bargali *et al.,* 20215), from land preparation to harvesting, making them central to the state's agricultural economy. Promoting vegetable value chains, improving irrigation facilities, and strengthening market linkages could significantly enhance the livelihoods of these farming households.

Agricultural Challenges in Hilly Areas

- *Lack of market access* is a major constraint for hill farmers, limiting their ability to sell produce at fair prices and often leading to distress sales.
- *Inadequate marketing infrastructure* necessitates the development of innovative institutional arrangements for the marketing of high-value crops like fruits and vegetables.

- *High participation of women* in vegetable cultivation and dairying compared to other crops, due to their greater involvement in planting, harvesting, weeding, transplanting, and livestock care.
- *Male out-migration* has left women responsible for most farm operations, increasing their workload and responsibilities.
- *Labour shortages* hinder the maintenance of terraces, irrigation systems, and livestock-based soil fertility practices.
- *Declining yields and land* abandonment are becoming more common due to reduced maintenance of productive resources.
- *Need for intervention* to stop the deterioration of productive infrastructure, improve farm labour productivity, and make farming more profitable in hilly regions.

Market-led Challenges Faced by Hill Farmers

1. Lack of market access: Farmers in hilly regions, such as Himachal Pradesh and Uttarakhand, often suffer from poor market access due to remoteness, lack of reliable transportation, and insufficient market infrastructure. This leads to farmers relying heavily on intermediaries, which diminishes their profit margins. The absence of modern market yards, cold storage facilities, and timely transportation often forces quick sales at low prices. Furthermore, most farmers lack access to updated market information, which limits their ability to negotiate better prices or choose profitable crops for cultivation. Furthermore, most farmers lack access to updated market information. Shukla et al. (2024) reported that market-related information ranks as the third most important requirement for enhancing the livelihood security of farmers.

2. Conventional Markets: The traditional supply chains are dominated by several intermediaries (traders, agents, wholesalers), and this complexity erodes farmer earnings. There is an urgent need for innovative institutional arrangements, like direct marketing models, cooperative societies, and technology-enabled platforms that connect farmers to consumers more efficiently. This results in reduced profits and income instability for hill farmers (Kumar *et al.,* 2025).

3. Post-Harvest Losses and Low Value Addition: Harvesting and handling losses are significant in hill farming due to reliance on manual methods and lack of storage or processing facilities. Post-harvest losses for crops like wheat and potatoes can reach up to 5–30%

depending on the crop and stage of handling. The lack of value addition facilities means farmers must sell raw produce at low prices, further impacting income of farmers.

4. Impact of Out-Migration: The migration of men from hilly regions to urban centres for work has led to women assuming greater farm responsibility. However, this shift has resulted in a shortage of labour needed to maintain terraces, irrigation systems, livestock, and soil fertility. Consequently, there is insufficient manpower for agricultural tasks.

5. Gender-Specific Constraints: Role of women in farming still face restricted access to land, credit, training, and decision-making. Women are heavily involved in vegetable cultivation and dairying in hilly areas, participating in activities like planting, weeding, harvesting, manure application, and animal care. Their participation surpasses that of men, particularly since male out-migration for employment opportunities has left women managing farms alone (Shahidullah *et al.,* 2023).

By considering the above marketing constraints, a study "Enhancing livelihood opportunity of the farming community through market linkages in Mid-hills regions" was formulated with following objectives:

Objectives

1. To increase the adoption of improved varieties of vegetables by farmers in the project area.
2. To impart primary processing skills to farmers and facilitate marketing of vegetables and fruits through formation of FIGs.
3. To encourage dairy and poultry in the study area by imparting skills and supply of critical inputs.

Coverage area

Present study was conducted in Nanital District of Uttarakhand state. Three villages were randomly selected from Bhimtal block of Nanital District. The selection procedure of respondents had shown below (fig. 1):

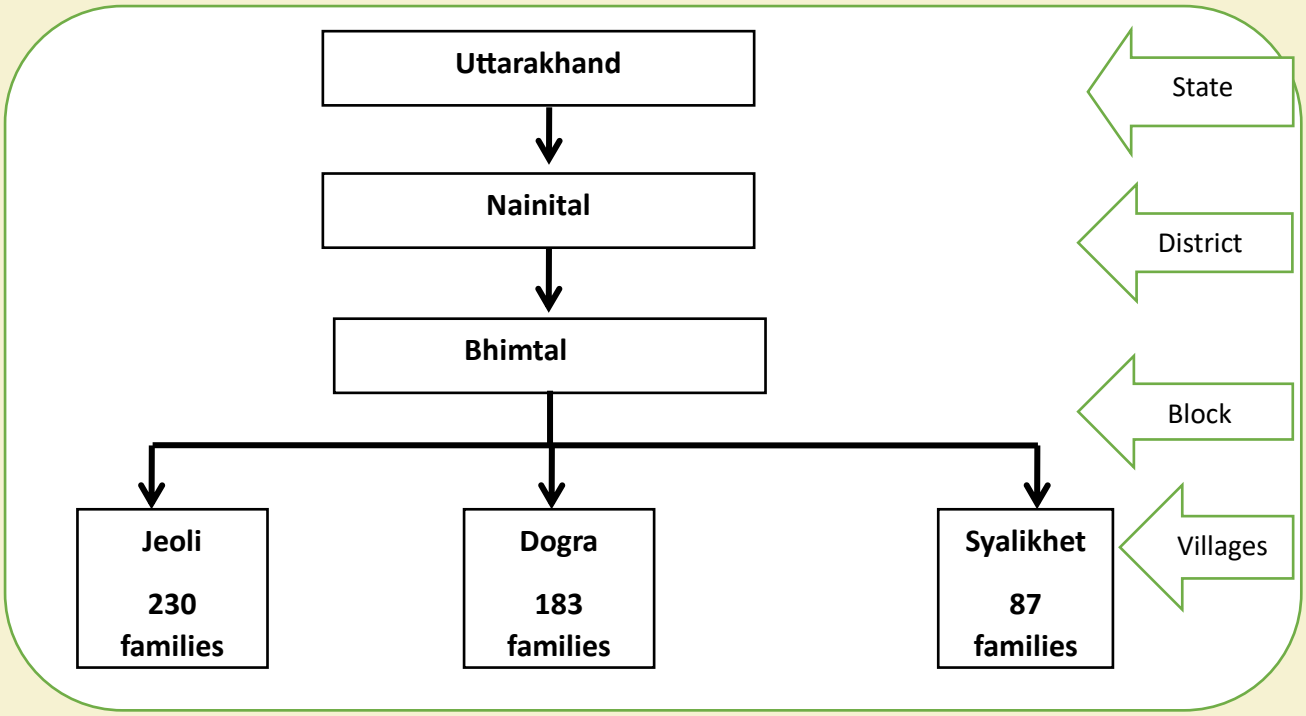

Fig. 1: Coverage area of Study

Methodology

- The farmers predominantly engaged in vegetable cultivation were provided seeds and seedlings of improved varieties developed for the hills of Uttarakhand by GBPUAT, VPKAS and local varieties that give good yield.
- Demonstrations were also set up in the farmers' fields and farmer-to-farmer interactions were arranged to encourage adoption.
- Pheromone traps and bio-agents were provided to the farmers and trainings were conducted during crop seasons to impart how-to knowledge.
- Washing tank, grader and Zero Energy Cool Chamber (ZECC) were installed in three villagers for washing grading and storing of fruits and vegetables. A Farmers' Interest Group was formed to leverage the advantages of bulk marketing.
- One Feed Block Machine and ten *Chara* Cutters were used to improve animal feeding practices in the study area. Backyard Poultry Cages were given to families primarily engaged in keeping birds for supplementary income to encourage poultry.
- Drudgery Reduction Kit were supplied to women dairy farmers to reduce work stress.

Agro-eco System Analysis of Mid-Hill region

The mid-hill regions of Uttarakhand, characterized by their unique agro-ecological conditions, present both challenges and opportunities for rural farmers seeking sustainable livelihoods. Traditionally grown crops like wheat, barley, mustard, lentil, rice, and pea. However, studies reveal a clear advantage in shifting to vegetable cultivation particularly cabbage, tomato, capsicum, and potato. Among various crops, cabbage being the most labour-intensive but also generates significantly higher monetary returns. Cabbage, in particular, has the highest output–input ratio among all vegetables. This makes vegetable farming more profitable and ecologically viable than conventional cereal or pulse production. The labour-intensive nature of vegetables also creates more local employment opportunities, which is essential in areas with small landholdings and limited mechanization.

Maximizing these benefits depends on establishing strong market linkages to ensure fair pricing, reduce post-harvest losses, and enhance farmers' bargaining power. Collective approaches through Farmer Producer Organizations (FPOs), cooperatives, and value chain development projects such as the Integrated Livelihood Support Project (ILSP) have proven effective in improving market access, infrastructure, and incomes. This combined approach of promoting high-value vegetable production and strengthening market connectivity offers a sustainable pathway for livelihood enhancement, income security, and socio-economic resilience for farming communities in the mid-hill regions.

Villages under Farmer FIRST Project (FFP) and adopted interventions

The table 1 presents an overview of three villages under the Farmer FIRST Project (FFP), each designated as a model for specific livelihood interventions suited to local resources and capacities. The initiatives focus on poultry rearing, beekeeping, and integrated vegetable–mushroom cultivation, leading to substantial income gains for participating farm families. These location-specific interventions demonstrate the potential of targeted enterprise development, appropriate technology adoption, and value addition in enhancing rural livelihoods in hill regions.

Table 1. Villages under Farmer FIRST Project (FFP) and adopted interventions

1. Syalikhet (The Poultry Village)	➢ A village of hill women, all males migrated. ➢ All marginal women farmers. ➢ Backyard poultry intervention, Uttara fowl, Kadaknath. ➢ Upto three-fold increase in income of each farm family.
2. Jeoli (The Honey Village)	➢ More than 2000 bee boxes ➢ Income increased triple as compared to the benchmark data. ➢ Honey processing Unit introduced. ➢ Wax plate making machine introduced.
3. Dogra (The vegetable and Mushroom village)	➢ Horticultures modules introduced. ➢ Poly tunnels, poly-mulching introduced. ➢ Mushroom bags were distributed. ➢ Income increased double as compared to the benchmark data.

Table 2. Interventions under different modules for enhancing livelihoods of Hill farmers

S.N.	Module	Interventions
1.	Horticulture	• Improved vegetable varieties • Quality plant material • Poly-tunnel establishment
2.	Livestock	• Backyard poultry • Distribution of goats • Feed and fodder supplements • Veterinary assistance and vaccination
3.	Honey/Bee keeping enterprise	• Honey production • Wax plate production.
4.	Mushroom Cultivation enterprise	• Raw material distribution for Mushroom cultivation. • Capacity Building for Mushroom cultivation.

Interventions under different modules for enhancing livelihoods of Hill farmers

Table 2 outlines the key livelihood enhancement modules implemented for hill farmers, encompassing horticulture, livestock, beekeeping, and mushroom cultivation. Each module integrates targeted interventions aimed at improving productivity, promoting diversification, and adding value to farm outputs. Collectively, these initiatives address both income generation and resource optimization, offering a holistic approach to strengthening the economic resilience of farming households in hill regions.

Enhancing Farmer–Scientist Interface

- Participatory identification of production technologies and value addition techniques.
- Joint technology dissemination activities in the form of workshops/ training programs in which successful vegetable cultivators will also act as resource persons.
- Visit by the scientists to farmers' field to document local best practices and use them for dissemination to other farmers.
- Constitution of joint monitoring team.

Case studies under different modules

A. Horticulture Module

Table 3. Case 1. Vegetables (Bottle Gourd, Cucumber, Tomato, Onion, Pea, Brinjal & French Bean)

1. Name of Technology	Pant Lauki-4, Pant Sankar Kheera-1, Pant Tomato-3, VL Piaz-3, Vivek Matar11, Pant Sabzi Matar-5, Pant Brinjal-4, V L Bean-2, Pant Bean-2.
2. Micro –Farming Situation	Mid hill region
3. Problem	The bench mark survey revealed that almost 80% of the farmers in the study area plant local varieties which give low yield. The farmers are either not aware of the improved varieties developed specifically for the mid hills of Uttarakhand by various research institutions or the actual adoption of these improved varieties is very low. The seeds and seedlings are often procured from the local market or middlemen through reciprocal arrangement by the

	farmers. Quality of these seeds is often poor or adulterated, because of which they get low output.
4. Potential Solutions	The farmers can be supplied seeds and seedlings of improved vegetable varieties suitable for the region at subsidized rate.
5. Nature of Intervention	Seeds and seedlings of Pant Lauki-4, Pant Sankar Kheera-1, Pant Tomato-3, VL Piaz-3, Vivek Matar11, Pant Sabzi Matar-5, Pant Brinjal-4, V L Bean-2, Pant Bean-2.
6. Source of Technology	G B Pant University of Agriculture and Technology, Pantnagar and Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora
7. Expected Out put	Lowering of input cost, use of genuine improved/ suitable varieties and increase in yield.
8. Area	Three villages
9. No. of Farm Families	400 farm families
10. Critical Inputs	Seeds and seedlings of (i) Pant Lauki-4 (ii) Pant Sankar Kheera-1 (iii) Pant Tomato-3 (iv) VL Piaz-3 (v) Vivek Matar11 (vi) Pant Sabzi Matar-5 (vii) Pant Brinjal-4 viii) V L Bean-2 (ix) Pant Bean-2.
11. Cost of each intervention	Rs 100/- / farmer/ year

Table 4. Case 2. Vegetables and cereals

1. Name of Technology	Bio-control measures
2. Micro–Farming Situation	Mid hill region

3. Problem	Pests and disease were listed among the top three important constraints to agricultural productivity in the study area. Pests and diseases not only lead to loss of crop but also increase in input cost due to repeated sowing. Pest and disease control in the hills of Uttarakhand is limited due to two reasons. Firstly, due to undulating terrain and frequent rains, it is not advisable to use chemical measures as they will contaminate the down-hill areas, especially the water bodies. Secondly, poor infrastructure and lack of agri-input outlets results in non-availability of control measures. Often the farmers end up buying spurious chemicals which have no effect leading to substantial loss.
4. Potential Solutions	Given the fragile nature of the ecosystem in the hilly regions of Uttarakhand and the environmental consequences of chemical control measures, the farmers can use bio-control measures in the form of pheromone traps and bio-agents to control pests and diseases. In the long run, use of bio-control measures will also help in marketing the produce of the state as organic produce, there by fetching higher price to the farmers.
5. Nature of Intervention	(i) Pheromone traps (ii) Bio-agents
6. Source of Technology	G B Pant University of Agriculture and Technology, Pantnagar.
7. Expected Out put	Increase in yield.
8. Area	Three villages
9. No. of Farm Families	400 farm families
10. Critical Inputs	(i) Pheromone traps (ii) Bio-agents
11. Cost of each intervention	(i) Pheromone traps – Rs 500/- (ii) Bio-agents – Rs 300/year/farmer

Table 5. Case 3. Fruits (Pear & Strawberry) and Vegetables (Cabbage, Cucurbits, Tomato, Okra, Onion, Potato, Pea & Radish)

1. Name of Technology	Post Harvest Management
2. Micro –Farming Situation	Mid hill region
3. Problem	Almost all households in the area grow fruits and vegetables for household consumption and supplementary income. During the peak season, there is a glut in production. The farmers sell the entire stock in one slot at a low price to get rid of the stock. This leads to very poor economic returns.
4. Potential Solutions	Primary value addition in the form of washing and grading the fruits and vegetable will yield better prices. Returns can also be enhanced if an appropriate storage facility is available.
5. Nature of Intervention	Washing, Grading and Storage of Fruits and Vegetables
6. Source of Technology	Commercial Firms
7. Expected Out put	Better prices due to grading and sequential release of produce into the market.
8. Area	Three villages
9. No. of Farm Families	475 farm families
10. Critical Inputs	(i) S.S Washing Tank -3 (ii) Graders - 3 (iii) Zero Energy Cool Chamber - 3
11. Cost of each intervention	(i) S.S Washing Tank – Rs 1,50,000/- (ii) Graders Rs 1,50,000/- (iii) Zero Energy Cool Chamber – Rs 1,50,000/-

B. Livestock Module

Table 6. Case 1. Buffalo and cow

1. Name of Technology	Feed Block Machine
2. Problem	Very few farmers give wheat straw, salt and mineral mixture to their cattle. Under feeding often results in late maturity, high mortality, poor lifetime performance, and infertility in cattle and buffaloes. Attention is paid to nutrition of the animals only when they are

	lactating. Cattle are often left to graze in the forest area and only hay is conserved for feeding of animals in the lean period. Scarcity of feed and fodder has been reported as one of the major constraints for adapting animal husbandry as a main occupation in the study area.
3. Potential Solutions	The farmers can prepare their own feed for the cattle by pooling crop residues and dried fodder residues refused by animals. This can be turned into nutritious feed for the animals by mixing other ingredients and micronutrients.
4. Nature of Intervention	Installation of the Feed Block Machine at community level.
5. Source of Technology	ICAR
6. Expected Out put	(i) Feed availability throughout the year at less cost. (ii) Increase in milk yield. (iii) Better nutrition to the animals.
7. No. of animals/birds	700 (approx.)
8. No. of Farm Families	528
9. Critical Inputs	(i) Feed Block Machine (ii) Crop residues (iii) Fodder waste (iv) Crushed cereals (v) Mineral mixture, etc.
10. Cost of each intervention	Rs 5,00,000/- for Feed Block Machine and Chaff Cutter. As this is a community level intervention, cost other inputs will be borne by the farmers.

Table 7. Case 2. Buffalo and cow

1. Name of Technology	Chara cutter
2. Problem	Almost all the households in the study area own cattle and dairying is a supplementary source of income for them. Majority of them are non-descriptive or local population of livestock. Shortage of feed and fodder is a major problem faced by livestock owners in the study area, though the magnitude of the problem varies with the socio-

	economic condition of the farmer. Farmers in the study area depend upon tree leaves and grasses grown in the forest area for the feeding the animals round the year. Usually, the feed is given to the animals without chaffing. Shortage of quality feed has an adverse effect on animal health as nutritional stress contributes increases susceptibility to diseases and low milk yield.
3. Potential Solutions	Chaffing of fodder and straw to small pieces and then feeding it to animals improves the nutritional value and digestibility of the feed. Chaffing also reduces wastage of feed and fodder.
4. Nature of Intervention	Installation of Chara Cutters for small groups of households.
5. Source of Technology	GBPUAT/ Commercial
6. Expected Out put	(i) Increase in fodder use efficiency. (ii) Better animal nutrition. (iii) Increase in milk yield.
7. No. of animals/birds	250 (approx.)
8. No. of Farm Families	204
9. Critical Inputs	Chara cutter
10. Cost of each intervention	Rs 5,000/- for each Chara Cutter. One chara cutter will be used by about 15-20 households.

C. Drudgery reduction kit

Table 8. Drudgery reduction kit

1. Name of Technology	Drudgery reduction kit
2. Problem	Village Suryatala has 204 households and all the household own milch cattle. The village has a Women Milk Cooperative. Dairying operations like cleaning milking, dung collection and disposal, etc. are mostly carried out by women. All these activities involve varying body postures like squatting, lifting, bending, etc. leading to fatigue and stress. On the long term, this may lead to physical injury and permanent damage to the body.

3. Potential Solutions	Various institutions have designed tools keeping the ergonomic characteristics of women in mind. These tools have been designed for women who are frequently engaged in agriculture and allied activities. Adoption of these tools can significantly reduce the stress faced by women.
4. Nature of Intervention	Drudgery reduction kit comprising of revolving stool, dung collector and Water bag.
5. Source of Technology	GBPUAT
6. Expected Out put	(i) Increase in work efficiency. (ii) Decrease in physical stress.
7. No. of animals/birds	-
8. No. of Farm Families	200
9. Critical Inputs	Drudgery reduction kit
10. Cost of each intervention	Rs 2,000/- for each kit comprising of Revolving Stool (Rs1100/-), Dung Collector (Rs 400/-) and Water Bag (Rs 500/-).

Table 9. Name of animal/bird: Hen

1. Name of Technology	Backyard Poultry Cage
2. Problem	All the households in village the Silaikhet are engaged in backyard poultry for supplementary income. Most of them sell eggs and but sale of birds is less frequent. Due to cool climate, eggs are in great demand in the area and if properly managed, backyard poultry can yield a handsome income to the households. However, due to lack of resources and space, most of the farmers leave their hens and young birds in the open leading to loss of birds due to injury.
3. Potential Solutions	Backyard poultry cages will provide a safe home for the birds at night when they are more likely to be attacked by predators and a convenient place for roosting.
4. Nature of Intervention	Supply of backyard poultry cages.
5. Source of Technology	Commercial
6. Expected Out put	Less damage to birds.

7. No. of animals/birds	450 (approx.)
8. No. of Farm Families	30
9. Critical Inputs	Backyard poultry cages
10. Cost of each intervention	Rs 5,000/- for each Backyard Poultry Cage.

Table 10. Collective Marketing of Fruits and Vegetables

1. Name of Technology	Formation of Farmers' Interest Group/ Commodity Interest Group
2. Micro –Farming Situation	Mid hill region
3. Problem	Many households in the area grow fruits and vegetables. The surplus produce is sold by the farmers' in the Haldwani Mandi or nearby places individually. As the size of the holdings is very small and is used partially for vegetable cultivation, quantity of the produce is small. Individual marketing not only increases the transaction cost but also fetches less price due to low volume.
4. Potential Solutions	The farmers' can form a Farmers' Interest Group/ Commodity Interest Group and pool their produce for sale through a community owned Retail Mart near the villages. This will not only decrease the transaction cost but they will be able to sell to buyers (like hotel, food processing units, etc.) in bulk there by getting better prices.
5. Nature of Intervention	Collective marketing by the Farmers' Interest Group/ Commodity Interest Group near the village or Mandi.
6. Source of Technology	N. A.
7. Expected Out put	Increase in profit due to decrease in transaction cost and bulk selling.
8. Area	Three villages
9. No. of Farm Families	475 farm families
10. Critical Inputs	Marketing support
11. Cost of each intervention	Rs 60,000/- per year to support farmers in establishing contact with the buyers, setting up of Retail Mart and other administrative costs.

	This is a group activity and any additional cost will be borne by the Farmers' Interest Group/ Commodity Interest Group.

Table 11. Mushroom Module

Parameter	Details
1. Name of Technology	Cultivation of button mushroom
2. Problem	As the farmers of the village found in difficulty of marketing of Oyster mushroom and also it was not preferred by the villager for their own home consumption, button mushroom was introduced for more production and income.
3. Potential Solution	The marketability and availability to consumers in fresh as well as semi-processed form is of great significance.
4. Intervention	Cultivation of button mushroom
5. No. of farm families	43 farm families
6. Cost of intervention	i) Mushroom bags- 2400/- ii) Preservative and other materials – 200/-
7. Total cost	Rs. 1,95,000/-

Table 12. Performance Indicators: Mushroom Module

Parameter	Details
a. Technical Observations	Better appearance and hygiene of the product and easy to handle
b. Economic indicators	Increase in income due to value addition of the product
c. Farmers reaction	Due to greater profit returns a greater number of farmer's groups may be attracted towards this technology intervention for value addition.

Market Linkage through different institutions in Mid Hill regions

A. Government initiatives

i) Simplified Application for Agricultural Loans (SAFAL): SAFAL is an online platform developed by Government of Odissa in make access to agricultural finance easier for farmers and agri-entrepreneurs. It offers a single-window solution to apply for over 300 term loan products from multiple banks, complete with guidance on model project reports and real-time tracking of applications. This reduces paperwork, speeds up loan processing, and improves farmers' ability to invest in inputs, infrastructure, and diversification of crops or enterprises.

ii) Mega Food Parks: These are large-scale agri-processing hubs established to integrate the farm-to-market value chain by providing facilities like cold storage, sorting, grading, packaging, and processing. By clustering multiple processing units with common infrastructure, farmers and entrepreneurs benefit from reduced logistics costs, value addition, and better market access, both domestically and for exports (MoFPI, 2025).

iii) Rural Marts: Set up under NABARD support, Rural Marts act as retail outlets in rural areas where farmers and rural entrepreneurs can sell their produce or processed goods directly to consumers. These help in reducing intermediary margins, promoting local products, and enhancing rural incomes by linking directly with buyers. During FY 2024-25, NABARD has sanctioned grant assistance of Rs2.98 crore as support towards 28 Rural Marts and 20 Mobile Vans (NABARD, 2025).

B. ITC initiatives

i) e-Choupal: An ITC initiative, e-Choupal installs internet-enabled kiosks in villages, managed by trained local farmers ("Sanchalaks"), giving farmers access to real-time market prices, weather forecasts, and best practice advisories. It empowers farmers to bypass middlemen by selling directly to ITC or other buyers, ensuring competitive prices.

ii) Chaupal Fresh: Chaupal Fresh outlets are retail stores that sell fresh fruits and vegetables directly sourced from farmers. By removing intermediaries, these outlets ensure farmers earn more while consumers get fresh produce at fair prices.

iii) Chaupal Sagar: A rural mall concept by ITC, Chaupal Sagar offers agricultural inputs, farm machinery, consumer goods, health services, and financial services alongside produce procurement. This one-stop centre serves as both a marketing outlet for farmers and an integrated service delivery point.

iv) Chaupal Cart: This initiative provides mobile vegetable vending carts to small entrepreneurs/vendors, enabling them to sell farm-fresh vegetables directly to consumers in towns and cities. It creates an additional retail channel for farmers while supporting small-scale vendor livelihoods.

C. Marketing initiatives by commodity interests' groups

i) Apni Mandi / Kisan Mandi: Popular in Punjab and Haryana, these are designated open markets where farmers sell produce directly to consumers. This eliminates middlemen, improves price realisation, and fosters stronger farmer-consumer connections.

ii) Rythu Bazars: Primarily in Andhra Pradesh and Telangana, Rythu Bazars are farmer-run markets supported by the state government to provide an affordable and direct selling space. They ensure fair prices for producers and reasonable prices for consumers.

iii) Shetkari Bazars: In Maharashtra, Shetkari Bazars function as farmer-run markets, enabling direct marketing without middlemen. They support small and marginal growers by giving them market access in urban and semi-urban centres.

iv) Krishak Bazars: Similar to other direct marketing initiatives, Krishak Bazars allow farmers to sell directly to consumers or institutional buyers, reducing marketing costs and enhancing the profitability of farm enterprises.

v) Mother Dairy Booths: Operated under the National Dairy Development Board framework, these outlets sell milk and milk-based products sourced directly from dairy cooperatives. They provide a reliable and remunerative marketing channel for dairy farmers, ensuring daily income flow.

Prevalent Marketing Models

A. Conventional marketing model

The Conventional Model (Fig. 2) is the traditional system of agricultural marketing in India, where farmers sell their produce primarily through local markets known as mandis, or to registered dealers and aggregators. This model is defined by its reliance on a wide network of intermediaries, including traders, agents, and state procurement systems that facilitate moving produce from farm to consumer. Its main advantage lies in established infrastructure and reach, offering farmers access to a broad spectrum of buyers and government procurement with minimum support prices, which can ensure some price stability. However, conventional models suffer from major lacunas: high transaction costs due to multiple intermediaries, lack of direct farmer control over pricing, vulnerability to market volatility, and possible exploitation via high commissions and delayed payments. Small and marginal farmers, in particular, are disadvantaged due to limited bargaining power and access to logistics.

B. Contract Farming (CF) marketing model

Contract Farming Model (Fig. 2) involves direct agreements between farmers and buyers (processors, manufacturers, or large distributors), stipulating terms of production, supply quantities, quality standards, and pricing. The core concept is to reduce marketing risk for farmers by providing assured markets and often technical and financial input support from the contracting company. The definition rests on pre-arranged contracts before crop sowing, which help guarantee a buyer and generally offer better returns compared to open market sales. Benefits include reduced market uncertainty, improved access to credit and technology, assured income, and potential for higher-quality production that meets market standards. The disadvantages are equally notable: limited flexibility for farmers in changing cropping decisions, risk of contractual breaches, dominance of the buyer in price negotiations, possibility of companies reneging on agreements, and restricted access for smallholders due to minimum volume requirements. In some cases, farmers may face exploitation if contract terms are not properly regulated.

C. Farmer Producer Organization (FPO) marketing model

The FPO Model (Fig. 2) is based on farmer collectives organized as producer companies or cooperatives, which pool resources for joint input procurement, collective marketing, processing, and brand development. FPOs are defined as autonomous farmer-owned enterprises registered under the Companies Act or cooperative societies, with the central goal of integrating small and marginal farmers into formal agricultural value chains and enabling

them to access remunerative prices with lower transaction costs. Key benefits include enhanced bargaining power, reduced dependence on intermediaries, lower input costs, improved income diversification, possibilities for value addition (processing and branding), and better market intelligence. However, the sustainability of FPOs depends heavily on institutional support, organizational capacity, and access to credit and market linkages. Key lacunas identified in research include lack of trust among members, inconsistent professional assistance, inadequate storage and logistics, and limited market/funding access—issues more acute in regions like Punjab, but somewhat mitigated in states with strong cooperative traditions like Gujarat.

The FPO model generally offers a more sustainable and inclusive approach for small and marginal farmers, especially in states with supportive institutional ecosystems (such as Gujarat). FPOs lower transaction costs, improve farmer bargaining position, and support income growth through collective action and value addition. However, without robust organizational and financial support, FPOs may struggle with sustainability—demonstrated by setbacks in Punjab. Conventional models remain widespread but are less favourable for farmer empowerment, while contract farming can benefit individual growers but may not address broader systemic inequities for smallholders. Therefore, the FPO model emerges as the most promising pathway, provided supportive policies and infrastructure are maintained to address its inherent challenges (Singh *et al.,* 2018).

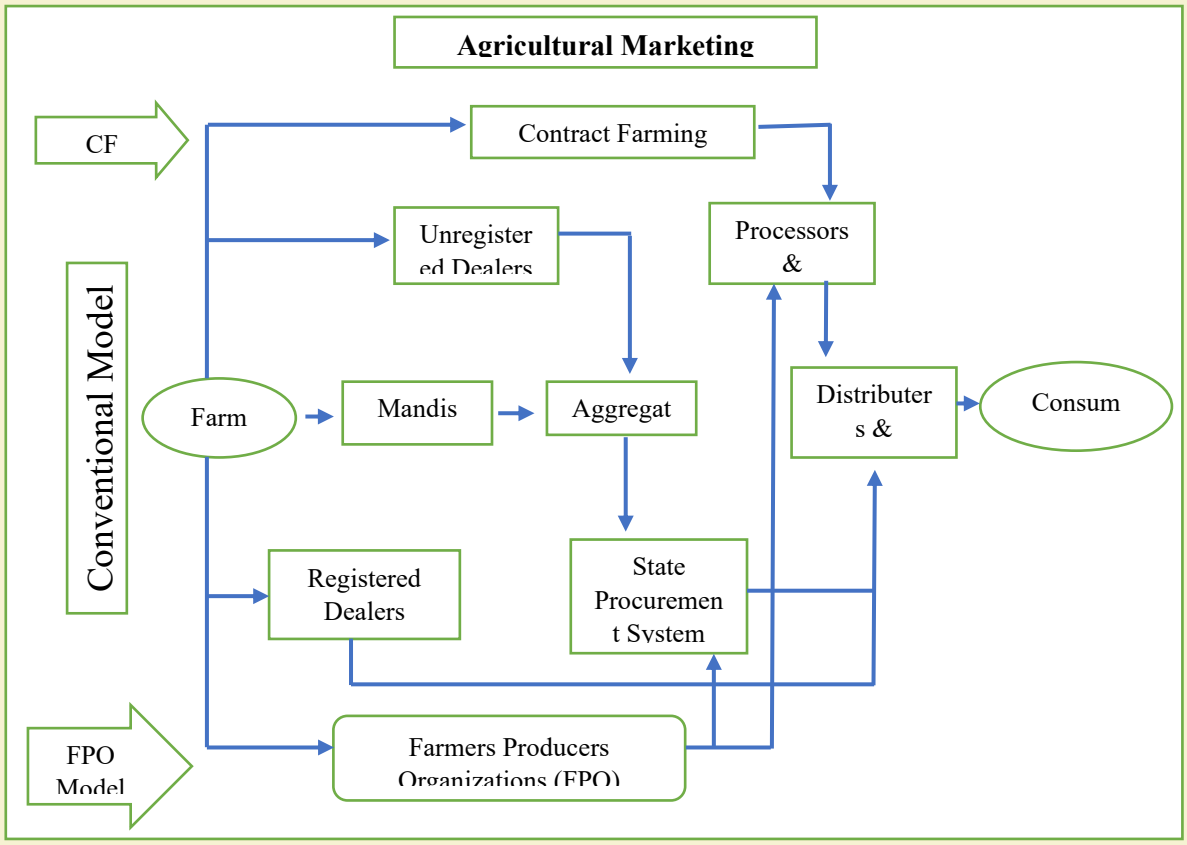

Fig. 2. Agricultural Marketing System

D. Amul Model/ Dairy Cooperative model

The fig. 3, illustrates the Amul Model/Dairy Cooperative model, a tiered structure that integrates smallholder milk producers into India's formal dairy sector. In this model, milk producers at the village level supply milk to Primary Milk Producers' Cooperative Societies, where milk is collected, weighed, and graded. These societies are responsible for making payments to producers, typically twice a day with deferred settlement of up to 15 days. The collected milk then flows to the District Cooperative Milk Producers' Unions. These unions handle the planning, processing, and packaging of milk and milk products, and make payments to the societies every 10 days. Next, processed products are transferred to the State Cooperative Milk Marketing Federation, which is charged with marketing and distribution to consumers. Consumers purchase these products from retail stores, parlours, and other outlets, providing cash payments that circulate back through the cooperative chain. Throughout the process, technical inputs, management support, and advisory services are provided, alongside veterinary care, artificial insemination, breeding services, cattle-feed, and training for farmers.

Fig. 3. Amul Model/ Dairy Cooperative model

This integrated system ensures that producers receive regular and fair payments, benefit from centralized processing and marketing, and gain access to professional services and inputs. The model is recognized for empowering small producers, streamlining supply chains, and delivering quality dairy products to consumers efficiently (Gandhi and Jain, 2011).

E. e-NAM Marketing Model

The National Agriculture Market (e-NAM) is a pan-India electronic trading platform launched in 2016 to integrate existing Agricultural Produce Market Committee (APMC) mandis, enabling transparent and competitive bidding for agricultural commodities. Its role is to provide farmers with wider market access, standardized quality assessment, and fair price discovery through an online system (Bandhavya *et al.,* 2023). The key benefits include reduced dependence on intermediaries, real-time price information, and direct digital payments to farmers. Its major advantages are improved market efficiency, enhanced farmer bargaining power, and the ability to sell produce to buyers across the country without geographical limitations.

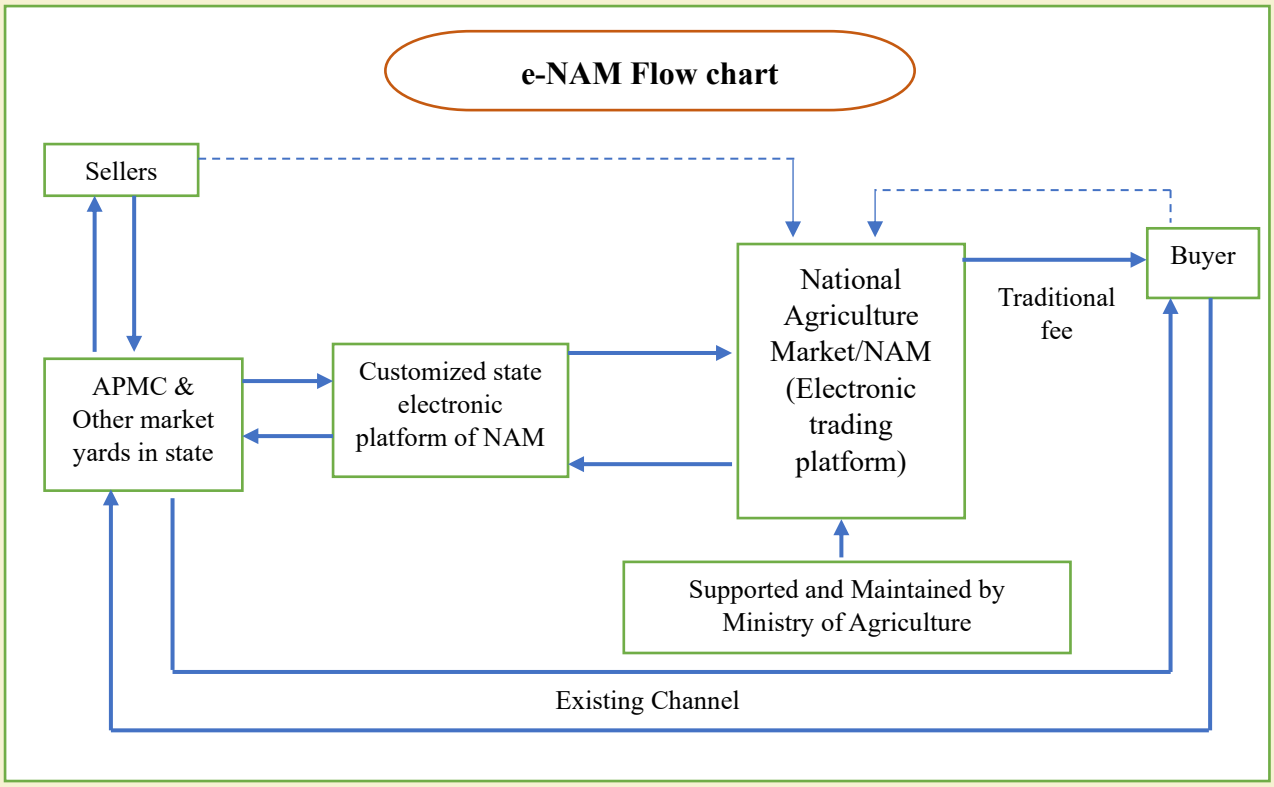

Fig. 4: e-NAM Marketing Model

The above figure (Fig. 4) illustrates how the National Agriculture Market integrates local APMC mandis and state market yards with a centralized electronic trading platform to connect sellers and buyers nationwide. Farmers or traders bring produce to the APMC, which links to the state's customized NAM platform, uploading product and quality details to the national system maintained by the Ministry of Agriculture. Buyers from anywhere can view listings, participate in bidding, and pay applicable traditional fees. Payments are routed directly to sellers, ensuring transparent transactions, faster settlements, and improved price discovery while expanding market access beyond local boundaries (Yadav *et al.,* 2021).

Growing significance of Mobile apps

Mobile phones are one of the most popular ICT tools for sharing information. Mobile phones facilitate real time information and also overcoming the barriers of remotely located villages. Millions of the farmers can access variety of information as per their need at same time with the help of various applications (Shukla *et al.,* 2024). Mobile applications are increasingly becoming vital tools for farmers, offering quick and convenient access to agricultural information and services through smartphones or tablets. These apps, downloadable from

online stores (free or paid) and often requiring internet connectivity, provide details on packages of practices, pest and disease management, and government schemes. They are especially valuable for delivering dynamic, real-time information such as weather forecasts, market prices, and personalized advisory services. By enabling informed decision-making, mobile apps help farmers improve productivity, reduce risks, and enhance profitability, ultimately serving as an essential bridge between technology and sustainable, modern agriculture.

Table 13. Mobile application and their users in India

Mobile Applications	**User's**
Agrimarket	25,249
Kisan Yojana	1,00,000-5,00,000
Kheti Badi	1,00,000-5,00,000
Modern Kheti	50,000-1,00,000
IFFCO Kisan	1,00,000 -5,00,000
Kisaan Market	10000-50000
Bazar Ke Bhav	50000-100000
Mandi Prices	10000-50000
RMLFarmer - Krishi Mitr	1,00,000-5,00,000
Digital Mandi India	50000
Agricultural Business	50000-100000
Agri Live	5000-10000

Table 14. Mobile Apps for marketing of agri-products in India

1.	eNAM Mobile App	https://play.google.com/store/apps/details?id=in.gov.enam&hl=en
2.	AgriMarket	https://apps.mgov.gov.in/descp.do?appid=989
3.	Digital Mandi India	https://play.google.com/store/apps/details?id=com.appkiddo.smartfarmer&hl=en

4.	Loop	https://play.google.com/store/apps/details?id=loop.org.digitalgreen.loop&hl=en

Partnership Building, Multi-stakeholders' convergence

The partnership-building and multi-stakeholder convergence approach involved collaboration with diverse organizations, including private enterprises, government departments, cooperatives, and educational institutions. This collaborative framework facilitated technology transfer, capacity building, and value chain development, thereby enhancing the effectiveness and sustainability of livelihood interventions in hill farming communities. The stakeholders in the study area are listed below:

- Patanjali Ayurveda,
- Himjoli,
- Department of Animal Husbandry,
- Krishi Vigyan Kendra, Jeolikote,
- Devbhumi Jaivik Utpaad Sangh Pvt. Ltd., Jeolikote,
- Arohan Consultancy Pvt. Ltd., Bhimtal
- National Agricultural Higher Education Project (NAHEP), Pantnagar.

Market Intelligence: Impact and scope

Market Intelligence is the process of collecting relevant information related to the existing market prices, domestic and global agricultural supply and demand conditions, policy environment and other relevant factors; converting those into usable form through scientific modelling and stakeholders' perceptions; and disseminating through effective means so that informed and effective decisions can be taken by the farmers and other stakeholders. Market intelligence plays a crucial role in agriculture by providing timely, accurate, and actionable information that empowers farmers and traders to make well-informed decisions. One of the key impacts of market intelligence is the increase in farmers' income through better decision-making about what crops to grow, when to harvest, and where and when to sell their produce. This reduces post-harvest losses by optimizing the timing and choice of market channels, leading to higher consumer satisfaction due to improved product availability and quality.

Moreover, market intelligence strengthens the bargaining power of farmers with traders, enabling a fairer share of the consumer rupee to reach producers. It also facilitates a more efficient allocation of productive resources by guiding farmers toward high-value crops that promise better financial returns, thereby enhancing overall farm profitability. Beyond benefiting farmers, market intelligence helps traders gain and maintain a competitive edge by better understanding market trends and consumer demand. It serves as a foundation for strategic decisions in production, marketing, and price forecasting, which is essential in the volatile agricultural markets. The scope of market intelligence extends to supporting policy-making, reducing transaction costs, and aiding in the commercialization of subsistence farmers through improved market linkages. Collectively, these benefits contribute to sustainable agricultural development by fostering a more responsive, competitive, and resilient agri-market system that promotes income growth, reduces risks, and enhances rural livelihoods.

Table 15. Usage/Types of Market Intelligence at different levels

Stakeholders	**Key Questions / Objectives**
Farmers	What crops to plant? When to plant? How to grow? Where to sell? When to sell?
Traders	What commodity to sell and purchase? Where and when to sell and purchase?
Consumers	What commodities to buy? Where to buy? When to buy?
Policy Makers	To ensure price and income stability. To protect consumers from high prices.

Out scaling of Technologies:

The process of out-scaling of technologies in the region is evident from how successful livelihood interventions in one village have been replicated by neighboring communities. In Syalikhet's surrounding hamlets, poultry farming has emerged as a profitable enterprise, motivating farmers in nearby areas to adopt it as a reliable income source. Similarly, the

demonstrated success of beekeeping in Jeoli village has inspired adjacent villages to take up apiculture, recognizing its potential for generating additional revenue and supporting crop pollination. In Dogra village, the adoption of commercial vegetable cultivation—both under protected structures (such as polyhouses) and through traditional open-field farming—reflects how proven agricultural technologies and practices spread across communities, enhancing income opportunities, promoting diversification, and strengthening the resilience of rural livelihoods.

Diffusion Sustainability of Interventions

The diffusion sustainability of interventions in the project area has significantly enhanced the economic viability and long-term sustainability of farming livelihoods. Farmers have experienced an increase in productive assets and inputs, such as the growth in poultry population, expansion of beekeeping enterprises with over 2,000 honeybee boxes, improved farm fencing, and higher egg sales, leading to steady income growth. The establishment of poly-tunnels has enabled smallholders to cultivate vegetables under protected conditions, ensuring year-round production and better-quality yields. Producer groups have moved up the value chain by selling processed produce at profitable prices instead of raw commodities, thereby capturing greater market value. Additionally, strong market linkages have been forged, connecting farmer collectives directly with buyers, while branding initiatives have enhanced product recognition and consumer trust. Together, these measures have not only improved immediate profitability but also strengthened the long-term resilience and sustainability of farming systems in the region.

Conclusion

The findings of this study affirm that robust market linkages are fundamental to enhancing the livelihood security and economic resilience of farming communities in India's mid-hill regions. Challenges such as limited access to infrastructure, male out-migration, gender-specific constraints, and post-harvest losses have historically hindered the realization of agricultural potential in these areas. However, targeted interventions including the introduction of improved crop varieties, collective marketing through FPOs and commodity interest groups, value addition through processing and storage, and the adoption of ICT-based tools have proven highly effective in bridging these gaps. The success stories from the "Honey Villages," "Poultry Villages," and "Vegetable and Mushroom Villages" highlight substantial gains in farm incomes, increased women's participation, and improved household food security.

Furthermore, the collaboration among multiple stakeholders—government, private sector, and local institutions facilitated technology transfer and strengthened value chains. These outcomes illustrate that a multi-pronged strategy, integrating technology, institutional innovation, and partnership building, can transform agricultural livelihoods even in resource-constrained hill environments. The sustainability of these interventions is evidenced by their replication in neighbouring villages and the long-term adoption of market-oriented practices. Thus, fostering strong market linkages and collective action emerges as a key pillar for sustainable development, income generation, and empowerment in hill agriculture.

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Blockchain Technology in Food Supply Chain Management: Revolutionizing Agricultural Sustainability

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Blockchain technology is associated with the vision of minimum government and maximum governance. it helps in diversifying self-governance and self-certification and it also explores the future aspects. It has also the potential to bring India on the top of ease of doing business ranking (Hon'ble Prime Minister of India: Narendra Damodardas Modi).

Abstract

In today's hyper-connected world, blockchain technology emerges as a transformative force, redefining trust, transparency, and efficiency in global food supply chains. This study aims to evaluate blockchain's impact on enhancing traceability, safety, and consumer trust in agricultural supply chains, with a focus on Indian and global initiatives. Leveraging its decentralized, immutable ledger, blockchain addresses critical challenges like food fraud, contamination, and inefficiencies, which affect 600 million people annually with foodborne illnesses, as reported by the World Health Organization. Case studies, including the Chhattisgarh PDS model, IBM Food Trust, Jharkhand's blockchain initiatives, Walmart's traceability system, and the NITI Aayog–Himachal Pradesh apple pilot, demonstrate significant outcomes: Walmart reduced mango traceability from 6 days to 2.2 seconds, while India's apple pilot enhanced export credibility (NITI Aayog, 2022). These initiatives showcase blockchain's ability to ensure real-time tracking,

authenticate certifications, and empower smallholder farmers, with India's fruit and vegetable exports reaching $1.5–2 billion from 2020–2022. The study highlighted blockchain's role in fostering sustainability and market access but identified challenges like low digital literacy, infrastructure limitations, and regulatory uncertainty. Future research should focus on cost-effective platforms, interoperability, and robust policy frameworks to scale adoption. Expanding pilot programs across diverse crops and regions will further validate blockchain's potential, positioning it as a cornerstone for resilient, transparent, and sustainable agri-food systems globally.

Keywords: *Agricultural Sustainability, Blockchain Technology, Food Safety, Food Supply Chain Management, Traceability, Transparency.*

Introduction

In today's hyper-connected world, where every click, transaction, and data exchange demands uncompromising security, transparency, and trust, blockchain technology stands out as a game-changing force poised to redefine the very architecture of global industries. At its core, blockchain is a form of distributed ledger technology (DLT) in which a continuously growing list of records called blocks is securely linked using cryptographic techniques and shared across a decentralised network of computers. This architecture ensures that once a transaction is recorded, it is immutable, verifiable, and resistant to unauthorised alterations, thereby fostering trust among participants without reliance on a central authority. While blockchain initially gained prominence through its application in cryptocurrency systems, where it serves as the backbone for secure peer-to-peer financial transactions, its capabilities extend far beyond digital currencies. Historical developments in blockchain reveal its applicability in addressing inefficiencies and vulnerabilities in traditional systems, such as supply chain management, where it enables real-time traceability; healthcare, where it ensures secure and interoperable patient records; and finance, where it streamlines cross-border payments and compliance processes. Thus, understanding blockchain's evolution from a niche cryptocurrency enabler to a robust digital infrastructure requires moving beyond the Bitcoin narrative to appreciate its multidisciplinary potential for enhancing accountability, operational efficiency, and data integrity in the global economy (Yasar, 2025). Indian Prime Minister Narendra Modi has expressed strong optimism about blockchain, viewing it as a "frontier technology opportunity" to drive India's economic growth and innovation (Modi, 2025a). While supportive of its applications across sectors, he has maintained a cautious stance on

cryptocurrencies, advocating for global regulations (Modi, 2025b). Modi highlighted blockchain's transformative role in agriculture, enhancing transparency and efficiency (Modi, 2025c), and positioned it as a catalyst for a broader "technology revolution" aligned with his vision of a self-reliant (*Atmanirbhar*) tech ecosystem (Modi, 2025d). His statements underscore the government's intent to leverage blockchain for sustainable development and global competitiveness.

History of Blockchain

The concept of maintaining records is not new. Around 7000 years ago, in the ancient civilization of Mesopotamia (modern-day Iraq), people used clay tablets to document trade, taxes, and goods exchanged. These primitive ledgers were preserved in temples, the most secure and trusted places of that era. This early system laid the foundation for the idea of a trusted record, a cornerstone principle that blockchain would build upon centuries later (AGAS, 2023). Fast forward to 1991, computer scientists Stuart Haber and W. Scott Stornetta introduced a method for time-stamping digital documents using cryptographic techniques to prevent tampering, marking the conceptual foundation of blockchain. In 1992, their model was enhanced by the incorporation of Merkle Trees, which allowed multiple documents to be grouped in one block and verified efficiently. Though the patent expired in 2004, it laid the groundwork for future digital systems. That same year, Hal Finney developed the Reusable Proof of Work (RPoW) system, a breakthrough in digital currency that addressed the issue of double-spending using a non-fungible proof-of-work mechanism. The most significant leap came in 2008 when an anonymous entity known as Satoshi Nakamoto published the Bitcoin whitepaper, launching the first practical application of blockchain through a decentralized digital currency system in 2009. Bitcoin's success established blockchain as a secure, decentralized, and transparent digital ledger technology with potential far beyond cryptocurrencies. By 2015, major corporations like IBM began exploring enterprise applications, leading to the development of the Hyperledger Fabric Project, a permissioned blockchain platform designed for use in sectors like agriculture, supply chain management, finance, and healthcare. IBM Food Trust, built on this framework, enables complete traceability and accountability in the food supply chain, showcasing blockchain's capacity to build trust and enhance efficiency. Today, blockchain is celebrated for its core features immutability, decentralization, transparency, and enhanced security making it ideal for storing sensitive data, verifying identities, and automating trust through smart contracts. As blockchain continues to evolve, it is revolutionizing how we

perceive data ownership, trust, and collaboration, offering a future where transactions and records are secure by design and transparency is built into every layer of digital interaction. From clay tablets to cryptographic chains, blockchain represents a technological culmination of humanity's enduring pursuit of trusted recordkeeping and secure systems in an increasingly digital world.

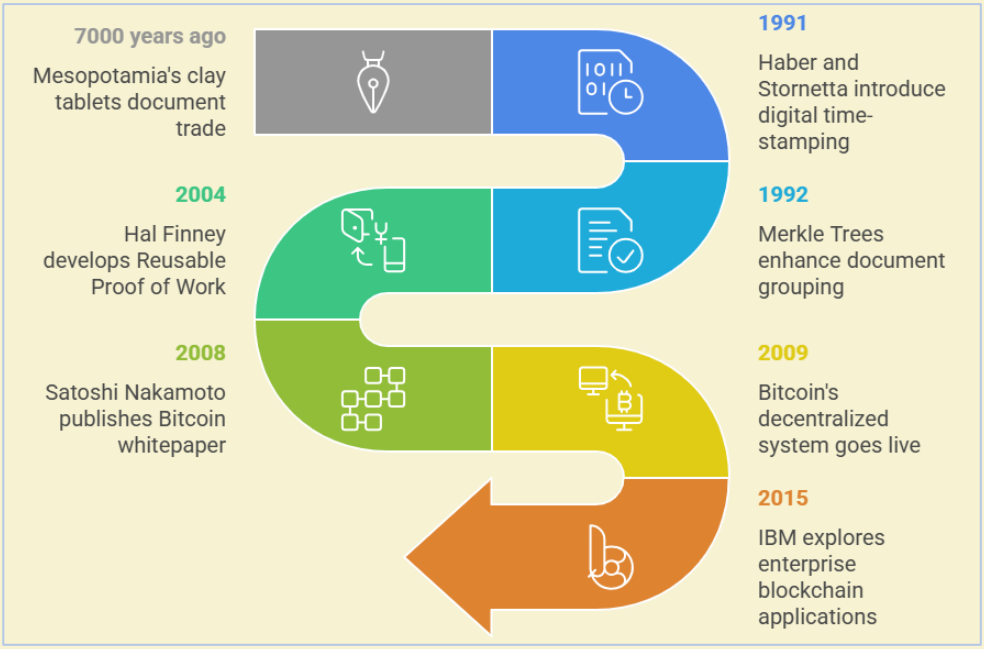

Fig.1. Evolution of Blockchain Technology

Blockchain in Food Supply Chain Management: Transforming Traceability, Safety, and Trust

The global food industry faces mounting challenges in ensuring safety, traceability, and transparency across complex supply chains. According to the World Health Organization, around 600 million people approximately 1 in 10 globally suffer from foodborne illnesses annually, underscoring the urgent need for improved food safety systems. Traditional supply chains often struggle with opacity, inefficiency, and fraud, making contamination sources hard to trace, triggering costly recalls, and eroding consumer trust (Kshetri, 2021; Xiong, 2020). Food fraud mislabeling, adulteration, and counterfeiting thrives without robust tracking, while inefficient logistics and unsustainable farming practices contribute to environmental damage (Vignesh, 2021). Blockchain technology offers a transformative solution, leveraging decentralization, transparency, and cryptographic security to create a shared, tamper-proof ledger accessible to all stakeholders (Funk, 2023). This "farm-to-fork" traceability fosters trust, enhances accountability, and reduces

fraud. Smart contracts automate secure transactions, eliminating intermediaries and improving efficiency (Kumar, 2021). By improving accessibility, quality, and safety, blockchain can revolutionize agricultural supply chains (Meshram, 2024).

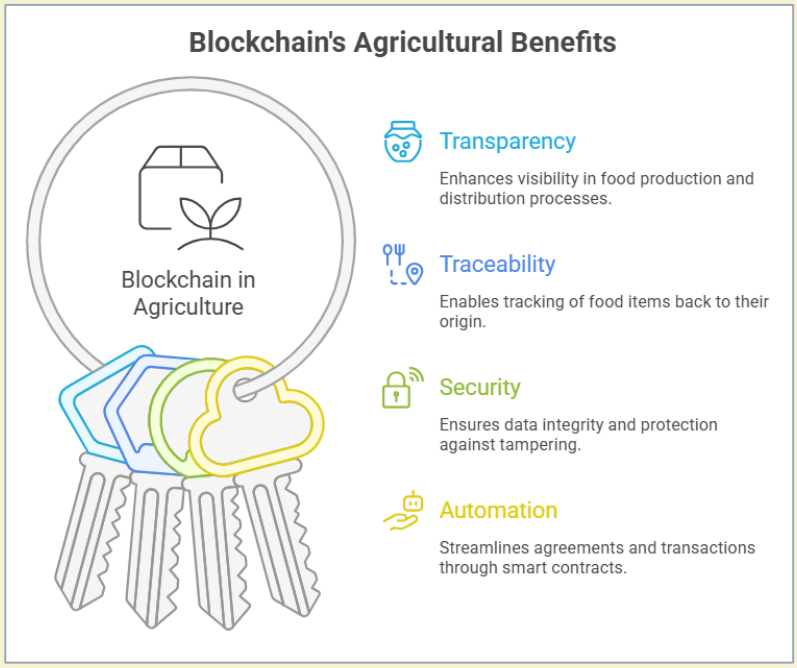

Fig.2. Benefits of Blockchain in Agriculture

In Indian agriculture, blockchain integrated with IoT sensors enables real-time tracking of production, storage, and distribution, ensuring authenticity and quality. Consumers can verify a product's origin and handling via QR codes or digital ledgers, making informed purchasing decisions. Between 2020 and 2022, India's exports of fresh fruits, vegetables, and processed products totaled billions of dollars, with major markets in Bangladesh, the UAE, Nepal, and the UK (APEDA, 2020–22). Despite significant trade volumes, untapped potential remains, and blockchain adoption could unlock higher value in global markets.

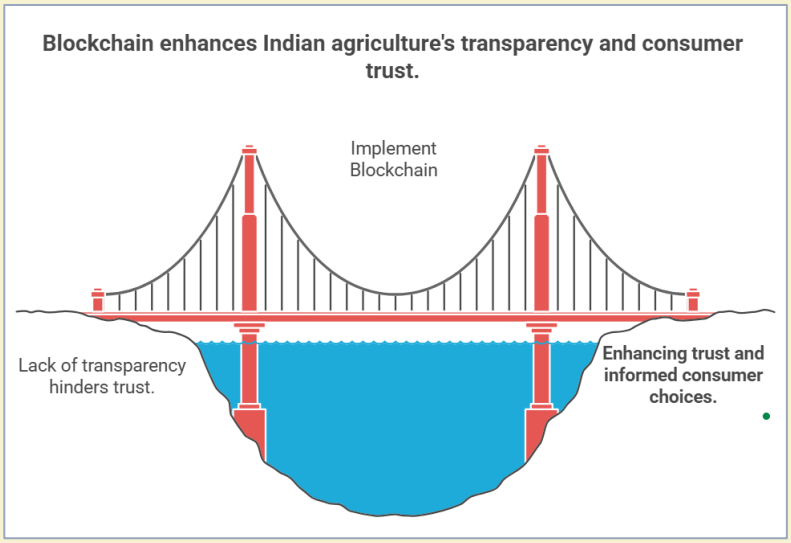

Fig. 3. Role of Blockchain in Indian Agriculture

Challenges in Traditional Food Supply Chains

The global food industry is facing complex challenges related to food safety, transparency, and traceability, particularly as supply chains become more globalized and multifaceted. According to the World Health Organization (WHO), 600 million people about 1 in every 10 globally suffer from foodborne illnesses each year. This alarming figure underscores the vulnerabilities in the current food system.

Traditional supply chains are often plagued by:

- **Lack of traceability**, making it difficult to identify contamination sources
- **Food fraud**, including mislabeling, adulteration, and counterfeit products
- **Environmental concerns**, such as high carbon emissions, deforestation, and overuse of resources
- **Inefficient logistics and opaque information flow**

These issues contribute to consumer distrust, regulatory challenges, and economic losses due to food recalls (Xiong, 2020; Vignesh, 2021).

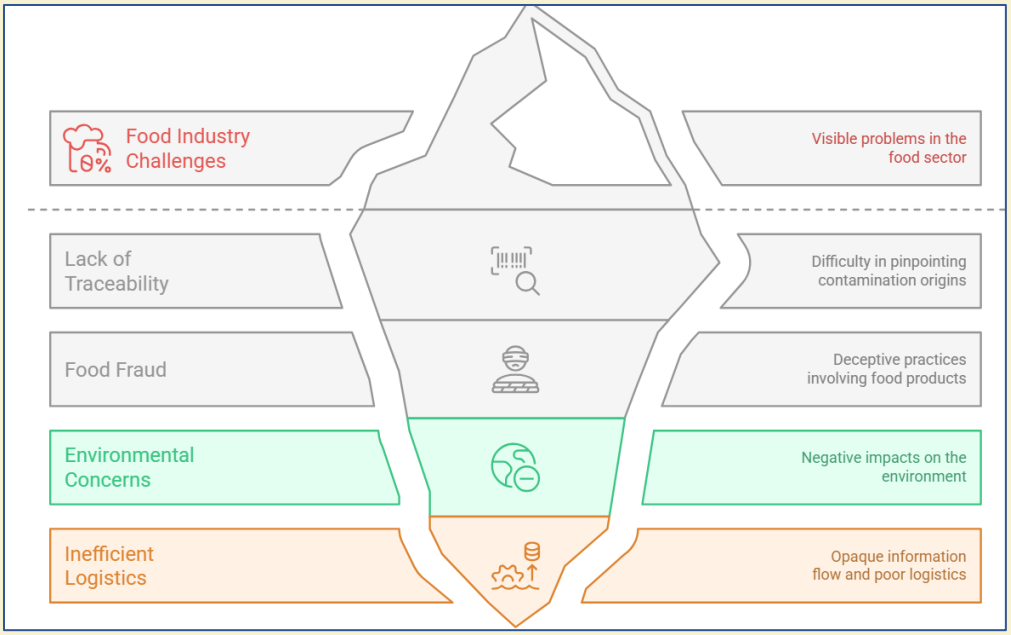

Fig. 4. Challenges in Traditional Food Supply Chains

Blockchain as a Game-Changer in the Food Supply Chain

Blockchain technology is transforming agri-food systems by offering a secure, transparent, and tamper-proof platform for tracking produce from "farm to fork" (Funk, 2023). Every stage planting, harvesting, processing, storage, transportation, and retail, is recorded on a distributed ledger, ensuring data integrity and real-time accessibility for all stakeholders. Agricultural supply chains typically involve producers, inspection and insurance agencies, logistics providers, banks, manufacturers, and importers. This complexity often leads to poor origin traceability, delayed information flow, and low trust in certifying bodies. Centralized systems are vulnerable to fraud, inefficiency, and contamination risks. For instance, the WHO reports that one in ten people globally suffer from foodborne illnesses annually, with up to 420,000 deaths. Incidents such as the 2008 melamine milk scandal in China and the 2013 horse meat fraud in the UK illustrate the consequences of opaque supply chains (Techskill Brew, 2022). Traditional paper-based traceability systems can take days or weeks to identify contamination sources, delaying corrective action and harming public trust. Blockchain addresses these issues through decentralization, immutability, and consensus-based validation. Farmers can record crop conditions, pesticide use, and certifications; processors log handling and packaging details; distributors capture inventory and storage conditions; retailers store product sales data. Products are tagged with unique IDs or QR

codes, enabling consumers to verify their journey instantly. Walmart, for example, reduced the time to trace mango origins from six days to 2.2 seconds using blockchain, significantly improving safety response times. In India, blockchain adoption is emerging as a strategic tool to boost exports, enhance quality, and modernize fragmented agricultural systems. The NITI Aayog–Himachal Pradesh apple farming pilot combines blockchain with IoT sensors to monitor production, storage, and distribution, ensuring compliance with global certification standards. Consumers can scan QR codes to confirm authenticity, while exporters gain credibility in high-value markets. Between 2020 and 2022, India exported $1.5–2 billion worth of fresh and processed fruits and vegetables, primarily to Bangladesh, the UAE, and Nepal. Blockchain integration can help tap untapped potential by improving trust and traceability (3.0 TV, 2023).

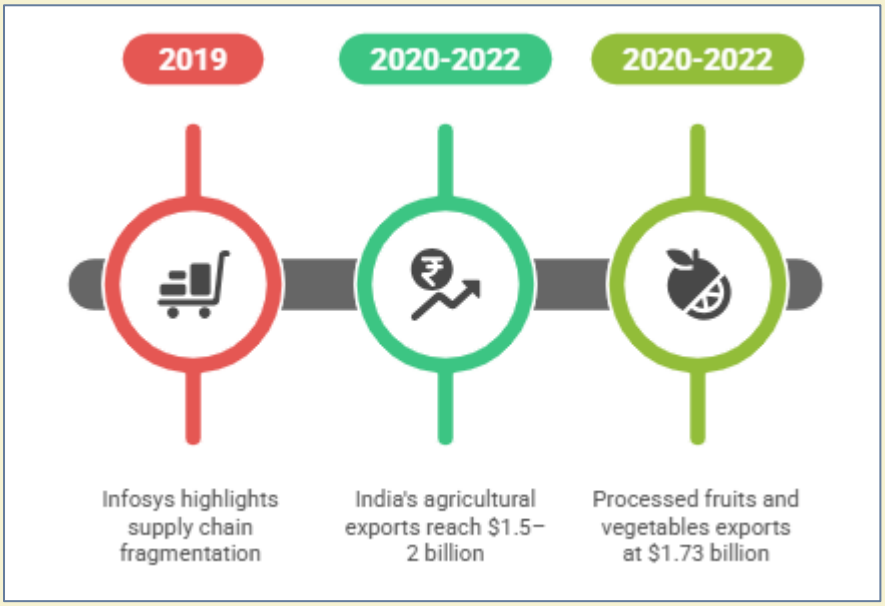

Fig. 5. Agriculture Transformation Through Blockchain

Infosys (2019) demonstrates blockchain's practical application through the example of Raj Kishor, a mango farmer in Uttar Pradesh, selling to Mohan of Royal Pulp Factory, who exports to Charles Becker in Germany. Every transaction—from crop inspection and certification to logistics, payment, and shipment—is recorded on the blockchain. This allows Charles to verify provenance instantly, boosting trust and acceptance of Indian produce internationally. By eliminating intermediaries through smart contracts, blockchain ensures secure transactions, minimizes fraud, and fosters transparency. Its adoption can make food systems more resilient, competitive, and

consumer-focused, while positioning Indian agriculture strongly in the global market (Kumar, 2021).

Integration of ICT and Digital Tools in Agriculture

Blockchain technology is transforming food supply chains by introducing transparency, traceability, and trust across all stages from production to consumption. It allows stakeholders to record and verify data in real-time, preventing fraud, ensuring quality control, and enhancing consumer confidence. By integrating blockchain with IoT and smart contracts, companies can monitor storage conditions, authenticate product origins, and streamline logistics, ultimately promoting food safety and sustainability.

Table 1: Key Applications of Blockchain in Food Supply

Category	Application	Benefits
Supply Chain Management	Tracking food from farm to fork (e.g., Walmart, IBM Food Trust)	Increases transparency, reduces fraud, shortens tracing time from days to seconds
Product Authentication	Verifying organic or certified produce (e.g., AgriDigital, Techrock)	Ensures food safety, combats counterfeiting, builds consumer trust
Logistics and Monitoring	Real-time monitoring of transport conditions (e.g., Intel with blueberries)	Prevents spoilage, monitors temperature, humidity, and light exposure
Ethical Sourcing	Preventing illegal fishing (e.g., WWF & TraSeable)	Supports ESG compliance, offers full catch-to-consumer transparency
Cross-border Trade	Tracking global food shipments (e.g., Alibaba)	Prevents counterfeits, simplifies customs clearance, ensures data integrity
Smart Contracts	Automated procurement and payment systems	Reduces delays, minimizes paperwork, ensures secure and automatic execution of agreements

Land Records & Subsidies	Blockchain-based land registration (e.g., pilot in Jharkhand)	Prevents fraud in land transactions, ensures fair subsidy distribution

In today's digital era, Information and Communication Technology (ICT) is revolutionizing how agriculture operates. ICT enables the collection, storage, analysis, and sharing of agricultural data, making farming more precise, responsive, and productive (Walter *et al.,* 2017).

Examples of ICT applications include:

- Remote sensing and satellite imagery for soil and crop monitoring (Brown, 2015)
- Mobile phones for market access, financial inclusion, and real-time decision-making (Kaske *et al.,* 2018)
- GPS and precision farming tools for field mapping and scouting (Yousefi and Razdari, 2015)

When integrated with blockchain, ICT enhances the value of data-driven farming, reduces operational costs, and supports smallholder farmers by providing equal access to market information and quality certifications.

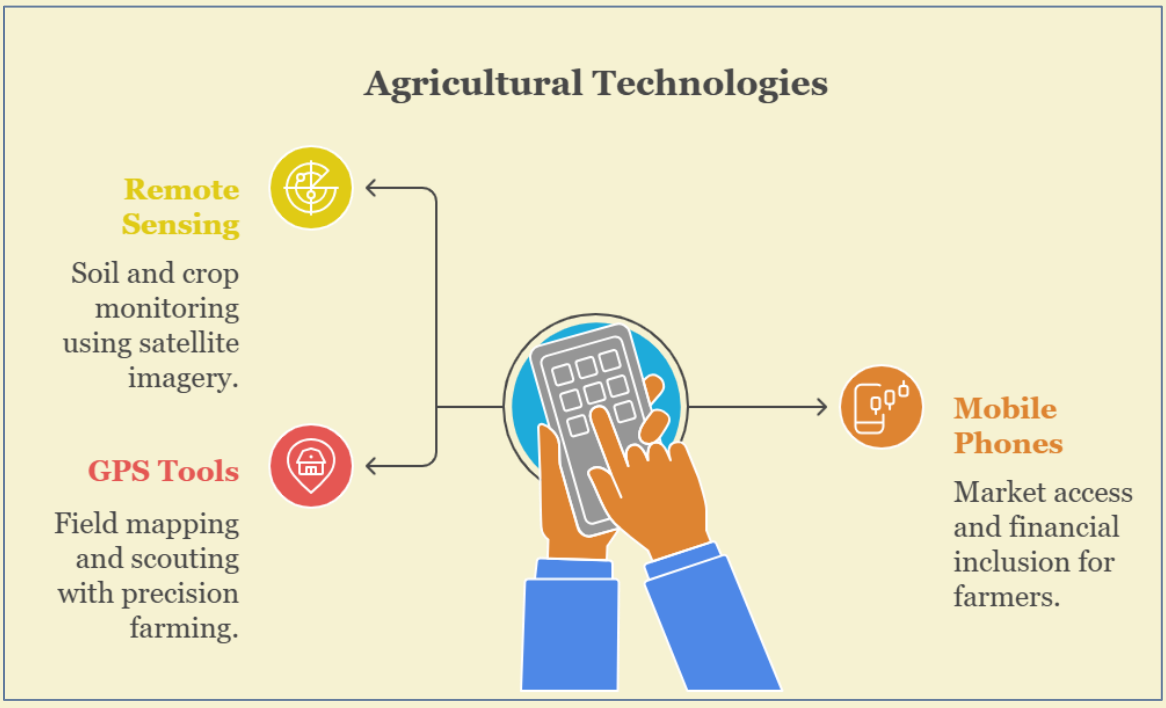

Fig. 6. ICT and Digital Tools in Agriculture

Case Studies on Blockchain in the Food Supply Chain

Blockchain technology is redefining food supply chain management by enhancing traceability, transparency, and trust from farm to fork (Kshetri, 2021). The following case studies illustrate its practical applications across global and Indian contexts, showcasing how blockchain and allied digital tools improve food safety, reduce inefficiencies, and empower producers (Kamilaris *et al.,* 2019).

Chhattisgarh Public Distribution System (PDS) Model

The Chhattisgarh Public Distribution System (PDS) Model, widely recognized as the "Food for All" initiative, represents a transformative step in food security governance in India (Sharma & Mishra, 2020). This model integrates the CORE-PDS (Centralized Online Real-time Electronic Public Distribution System), leveraging Information and Communication Technology (ICT) tools to ensure efficiency, accountability, and real-time monitoring (Sharma & Mishra, 2020). Implemented in phased stages, it began with the digitization of the distribution process, followed by Aadhaar-based biometric authentication, and culminated in online monitoring and audit trails (Gupta & Singh, 2022). This structured approach has significantly reduced leakages, ensured that rations reach the intended beneficiaries, and enhanced overall transparency in food grain distribution (Gupta & Singh, 2022).

IBM Food Trust

IBM Food Trust, a pioneering blockchain-based solution, is revolutionizing traceability in food systems by offering end-to-end visibility from seed to shelf (IBM, 2023). Used globally by companies such as Walmart, the platform records every transaction and movement of food products, verifying their authenticity and quality (Walmart, 2021). In the context of organic farming, IBM Food Trust plays a crucial role by digitally validating organic certifications, thereby instilling confidence among consumers (Kamilaris *et al.,* 2019). For farmers, especially those engaged in sustainable agriculture, this creates opportunities for better market access and premium pricing (IBM, 2023). Ultimately, the system fosters trust, reduces spoilage, and supports informed decision-making across the supply chain (Walmart, 2021).

Jharkhand

Inspired by such models, Jharkhand has initiated blockchain applications in agricultural governance (Kumar & Sharma, 2023). While the case study is still evolving, key areas of implementation include digitization of land records, transparent procurement of agricultural produce, and pilot ration distribution projects integrated with Aadhaar-based authentication (Kumar & Sharma, 2023). These measures mirror the innovations seen in Chhattisgarh, aiming to reduce corruption and ensure targeted delivery of resources (Gupta & Singh, 2022). By adopting blockchain technologies, Jharkhand is making strides toward a more accountable and efficient agri-supply and welfare ecosystem, aligning with national objectives of digital inclusion and food security (Kumar & Sharma, 2023).

Walmart and IBM Food Trust Collaboration

Blockchain technology has proven transformative in enhancing traceability and consumer trust in global food supply chains (Walmart, 2021). A notable example is the collaboration between Walmart and IBM through the IBM Food Trust platform (IBM, 2023). Faced with the challenge of slow food traceability, Walmart adopted this permissioned blockchain to digitize and streamline the tracking process of produce such as mangoes (Walmart, 2021). As a result, the time required to trace contaminated mangoes reduced drastically from 6 days to just 2.2 seconds (IBM, 2023). This successful implementation not only improved food safety and transparency but also encouraged other major companies like Nestlé and Carrefour to join the initiative (Kamilaris *et al.,* 2019).

NITI Aayog and Himachal Pradesh Pilot

In India, blockchain is gradually being integrated into the agricultural sector through pilot programs and public-private partnerships (NITI Aayog, 2022). One such initiative by NITI Aayog and the Himachal Pradesh government involved using blockchain and IoT technologies in apple cultivation (NITI Aayog, 2022). This system recorded vital information like pesticide use, weather data, and harvest details on an immutable ledger, accessible via QR codes for both consumers and exporters (Kumar & Sharma, 2023). The pilot significantly improved the credibility and export potential of Himachali apples, and there are plans to replicate this model for other fruits such as

grapes and mangoes, thus supporting smallholder farmers and boosting market transparency (NITI Aayog, 2022).

Table 2: Comparative Overview of Blockchain and ICT-Based Food Supply Chain Models in India and Globally

Model / Initiative	Key Features	Technologies Used	Outcomes / Impact
Chhattisgarh Public Distribution System (PDS) Model – "Food for All"	Phased implementation: digitization of distribution, Aadhaar-based biometric authentication, online monitoring, and audit trails. Real-time tracking of ration distribution.	CORE-PDS (Centralized Online Real-time Electronic PDS), ICT tools, Aadhaar authentication.	Reduced leakages, ensured targeted delivery of rations, enhanced transparency and accountability in food grain distribution.
IBM Food Trust	End-to-end food traceability from seed to shelf; validation of organic certifications; used by Walmart and other global companies.	Permissioned blockchain, digital certification, IoT-enabled tracking.	Improved authenticity verification, reduced spoilage, better market access for farmers, premium pricing for sustainable produce, enhanced consumer trust.
Jharkhand Blockchain Initiatives	Digitization of land records, transparent agricultural procurement, Aadhaar-linked pilot ration distribution projects.	Blockchain technology, Aadhaar authentication.	Reduced corruption, improved targeted delivery of welfare benefits, enhanced efficiency in agri-supply governance.

Walmart–IBM Collaboration	Fast-tracking traceability of produce (e.g., mangoes) to ensure food safety.	IBM Food Trust blockchain platform.	Reduced traceability time from 6 days to 2.2 seconds, improved transparency, inspired adoption by Nestlé, Carrefour.
Himachal Pradesh Apple Blockchain Pilot (NITI Aayog)	Immutable record of pesticide use, weather, and harvest data; consumer access via QR codes.	Blockchain, IoT sensors, QR code technology.	Improved export credibility of Himachali apples, enhanced consumer confidence, scalable to other crops (grapes, mangoes), supported smallholder farmers.

Challenges to Blockchain Adoption

Despite its transformative potential, the adoption of blockchain technology in Indian agriculture faces multiple hurdles. A significant barrier is the lack of awareness among farmers and stakeholders, which limits the willingness to adopt such innovations (Yadav *et al.,* 2020; Ahmad & Qahmash, 2021). Low digital literacy in rural communities further restricts the effective use of blockchain-based platforms (Saxena, 2022; Ahmad & Qahmash, 2021). Infrastructure limitations, including poor internet connectivity and limited access to smartphones especially in remote areas create additional obstacles (Ahmad & Qahmash, 2021). Moreover, scalability remains a concern, as deploying blockchain solutions across India's vast and diverse agricultural landscape requires substantial technological and financial resources (Ahmad & Qahmash, 2021; Meshram, 2024). Regulatory uncertainty due to the absence of a comprehensive legal framework for blockchain applications can discourage both public and private investment (Yadav *et al.,* 2020; Ahmad & Qahmash, 2021; Kamble *et al.,* 2019). Additionally, interoperability issues between various blockchain platforms and legacy systems pose a technical challenge, as seamless data exchange is essential for maximizing blockchain's efficiency in agri-supply chains (Ahmad & Qahmash,

2021). Addressing these challenges through policy support, infrastructure development, farmer training, and standardization will be crucial for leveraging blockchain to enhance transparency, efficiency, and sustainability in Indian agriculture (Yadav *et al.,* 2020; Ahmad & Qahmash, 2021).

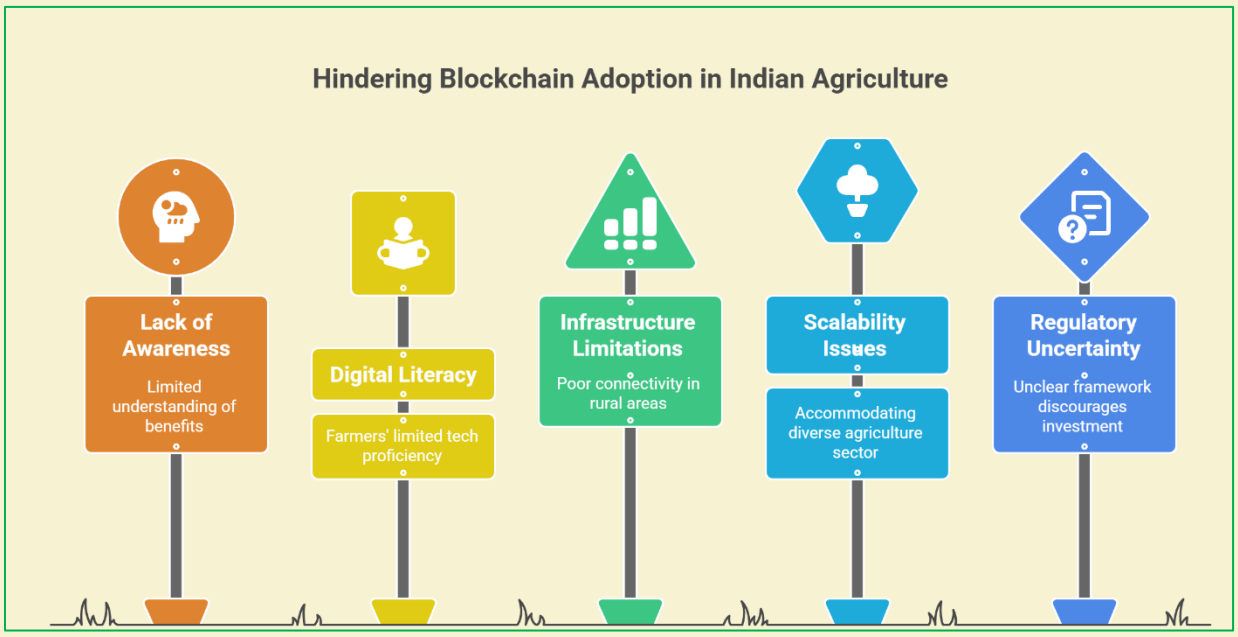

Fig 7 Challenges to Blockchain Adoption

Existing Initiatives and Future Prospects

Several initiatives are underway in India to explore and implement blockchain technology in agriculture:

- Government Initiatives: Some state governments are piloting blockchain-based solutions for tracking agricultural produce and providing farmers access to credit (NITI Aayog, 2020).
- Private Sector Initiatives: Startups and established companies are developing blockchain-based platforms for supply chain management, traceability, and quality assurance (Ahmad & Qahmash, 2021; Saxena, 2022).
- Pilot Projects: Pilot projects test the feasibility and effectiveness of blockchain in various agricultural settings (NITI Aayog, 2020).

The future prospects are promising: as awareness grows and infrastructure improves, more farmers and businesses are likely to adopt blockchain-based solutions. Government support in funding, regulatory frameworks, and pilot support—will be crucial (NITI Aayog, 2020; Saxena, 2022).

Conclusion

Blockchain technology has emerged as a transformative force in modernizing food supply chains by enhancing transparency, traceability, and trust from production to consumption. Through its decentralized, tamper-proof, and real-time data-sharing capabilities, blockchain addresses critical challenges such as food fraud, contamination, inefficiency, and lack of trust in certification systems. Case studies from India and abroad demonstrate its potential to improve food safety, streamline logistics, and empower both producers and consumers. Initiatives like the NITI Aayog Himachal Pradesh apple pilot and private sector models, such as Infosys Blockchain and IBM Food Trust, highlight its scalability and adaptability to diverse agricultural contexts. The scope of this study extends to exploring blockchain's application in agricultural traceability, quality assurance, and export competitiveness, with emphasis on empowering smallholder farmers, integrating IoT-based monitoring, and building consumer confidence in global markets. Future research should focus on developing cost-effective, farmer-friendly blockchain platforms, improving interoperability between systems, and creating robust policy and regulatory frameworks to encourage adoption. Addressing infrastructure limitations, digital literacy, and scalability challenges will be crucial. Pilot programs should be expanded across different crops and regions to assess long-term impact. Ultimately, blockchain can be a cornerstone in building resilient, transparent, and sustainable agri-food systems for the future.

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वैश्विक भूख सूचकांक को कम करने के लिए खाद्य एवं पोषण सुरक्षा विषयक तीन दिवसीय वर्चुअल मोड में राष्ट्रीय प्रशिक्षण आरंभ

पूसा (एसएनबी)। डॉ. राजेंद्र प्रसाद केंद्रीय कृषि विश्वविद्यालय, पूसा, बिहार द्वारा मैनेज हैदराबाद के सहयोग से भारत के संदर्भ में वैश्विक भूख सूचकांक को कम करने के लिए खाद्य एवं पोषण सुरक्षा विषय पर आधारित 3 दिवसीय राष्ट्र स्तरीय वर्चुअल मोड प्रशिक्षण कार्यक्रम का आयोजन किया गया। जिसका शुभारम्भ करते हुए कृषि स्नातकोत्तर महाविद्यालय के अधिष्ठाता एवं प्रसार शिक्षा निदेशक, डॉ. मयंक राय ने कहा कि समय आ चुका है भारत को दलहन व तिलहन उत्पादन के क्षेत्र में भी आत्मनिर्भर बनने की और विदेशों पर निर्भरता कम रहने की । उन्होंने बल देते हुए कहा कि भारत द्वारा परीक्षण की जा रही जैव-संवर्धित (बायो-फोर्टीफाइड) फसलें किस प्रकार खाद्य सुरक्षा को बढ़ावा दे सकती है वही जलवायु परिवर्तन के प्रभाव को कम करने से जुड़े अपनी बातों को रखा वही डॉ. उषा सिंह, अधिष्ठाता सामुदायिक विज्ञान महाविद्यालय ने आहार विविधता के माध्यम से पोषण सुरक्षा प्राप्त करना एवं विश्वविद्यालय के कई पोषण युक्त उत्पादों के माध्यम से कैसे कुपोषण को कम किया जा सकता है उस पर बल दिया। डॉ ऋतंभरा सिंह ने एफपीओ एवं मूल्य श्रृंखला और बाजार संपर्क ने कुपोषण को कैसे कम किया जा सकता है के बारे में विस्तार से चर्चा की। वैज्ञानिक, केरल कृषि विश्वविद्यालय डॉ. अपर्णा राधाकृष्णन,ने उर्ध्वाधर खेती और केरल मॉडल को अपनाकर खाद्य और पोषण सुरक्षा के लक्ष्य की प्राप्ति से जुड़ने पर चर्चा किया। बताते चलें कि इस प्रशिक्षण में 21 राज्यों के 68 विभिन्न संस्थानों से 214 प्रशिक्षणार्थी हिस्सा ले रहे है। आंकडों की बात करें तो भारत में पाँच वर्ष से कम उम्र के 35.5 प्रतिशत बच्चे कुपोषण के कारण अविकसित ट्रस्टंटेड) है। इसका मुख्य कारण जीवन के प्रारंभिक वर्षो में पौष्टिक आहार की कमी है। इसे सुधारने के लिए गर्भवती महिलाओं और बच्चों को संतुलित आहार देना, छह महीने तक केवल स्तनपान कराना, टीकाकरण, स्वच्छ पानी और स्वच्छता सुनिश्चित करना जरूरी है। साथ ही, पोषण जागरूकता और सरकारी योजनाओं जैसे आंगनवाड़ी व मिड-डे मील को मजबूत करना भी आवश्यक है, कार्यक्रम का संचालन डा. सुधानन्द प्रसाद लाल ने किया जबकि धन्यवाद ज्ञापन डा. सत्य प्रकाश ने किया।

प्रशिक्षण में शामिल प्रशिक्षु।

Rashtriya Sahara 25-06-2025

दैनिक भास्कर, मुजफ्फरपुर, बुधवार, 25 जून, 2025 | 14

भास्कर 25/6/25 पेज 14

कार्यक्रम • डॉ. राजेंद्र प्रसाद केंद्रीय कृषि विवि की ओर से तीन दिवसीय राष्ट्रीय स्तरीय प्रशिक्षण

देश को दलहन व तिलहन उत्पादन में आत्मनिर्भर बनाने की जरूरत : मयंक

भास्कर न्यूज | पूसा

डॉ. राजेंद्र प्रसाद केंद्रीय कृषि विश्वविद्यालय पूसा द्वारा मैनेज हैदराबाद के सहयोग से 3 दिवसीय राष्ट्रीय स्तरीय (वर्चुअल मोड) प्रशिक्षण कार्यक्रम का आयोजन किया गया। प्रशिक्षण कार्यक्रम का विषय भारत के संदर्भ में वैश्विक भूख सूचकांक को कम करने के लिए खाद्य एवं पोषण सुरक्षा पर आधारित था। कार्यक्रम का शुभारंभ करते हुए कृषि स्नातकोत्तर महाविद्यालय के अधिष्ठाता एवं प्रसार शिक्षा निदेशक डा. मयंक राय ने कहा कि समय आ चुका है कि भारत दलहन और तिलहन उत्पादन में भी आत्मनिर्भर बने और विदेशों पर निर्भरता कम करें। उन्होंने कहा कि भारत द्वारा परीक्षण की जा रही जैव-संवर्धित (बायो-फोर्टीफाइड) फसलें खाद्य सुरक्षा को बढ़ावा दे सकती हैं और जलवायु परिवर्तन के प्रभाव को भी कम कर सकती हैं। डॉ. उषा सिंह, अधिष्ठाता सामुदायिक विज्ञान महाविद्यालय ने आहार विविधता के माध्यम से पोषण सुरक्षा प्राप्त करने एवं विश्वविद्यालय के कई पोषण युक्त उत्पादों के माध्यम से कैसे कुपोषण को कम किया जा सकता है इस पर बल दिया। डॉ. ऋतंभरा सिंह ने किसान उत्पादक संगठन (एफपीओ), मूल्य श्रृंखला और बाजार संपर्क द्वारा कुपोषण को कैसे कम किया जा सकता है इस पर विस्तार से चर्चा की। डॉ. अपर्णा राधाकृष्णन वैज्ञानिक केरल कृषि विश्वविद्यालय ने ऊर्ध्वाधर खेती और केरल मॉडल को अपनाकर खाद्य और पोषण सुरक्षा के लक्ष्य को कैसे प्राप्त किया जा सकता है इस पर अपनी ज्ञान साझा की। प्रशिक्षण कार्यक्रम में 21 राज्य के 68 विभिन्न संस्थानों के 214 प्रशिक्षणार्थी भाग ले रहे हैं। डा. सुधानन्द प्रसाद लाल ने कार्यक्रम का संचालन किया। बता दें कि भारत में पाँच वर्ष से कम उम्र के 35.5 प्रतिशत बच्चे कुपोषण के कारण अविकसित (स्टंटेड) में हैं। इसका मुख्य कारण जीवन के प्रारंभिक वर्षों में पौष्टिक आहार की कमी है। इसे सुधारने के लिए गर्भवती महिलाओं और बच्चों को संतुलित आहार देना, छह महीने तक केवल स्तनपान कराना, टीकाकरण, स्वच्छ पानी और स्वच्छता सुनिश्चित करना जरूरी है। इसके अलावे पोषण जागरूकता और सरकारी योजनाओं जैसे आंगनवाड़ी व मिड-डे मील को मजबूत करना भी आवश्यक है। धन्यवाद ज्ञापन डा. सत्य प्रकाश ने किया।

ऑनलाइन मोड में मीटिंग करते विशेषज्ञ।

शिविर में दी गई वैज्ञानिक तरीके से मछली पालन की जानकारी

समस्तीपुर | डॉ राजेन्द्र प्रसाद कृषि विश्वविद्यालय पूसा एवं बिहार के मत्स्यकी महाविद्यालय, ढोली द्वारा जिला मत्स्य कार्यालय समस्तीपुर में मत्स्य उपचार शिविर का आयोजन किया गया। इसमें समस्तीपुर के विभिन्न मत्स्यपालकों को निःशुल्क जल परीक्षण एवं मत्स्य की अभिवृद्धि के लिए परामर्श दिया गया। इस मौके पर मात्स्यिकी महाविद्यालय के सहायक प्राध्यापक डॉ राजीव कुमार ब्रह्मचारी ने उपस्थित मत्स्य पालकों को वैज्ञानिक तरीके से आधुनिक मत्स्य पालन के बारे में बताया गया। साथ ही पानी की गुणवत्ता, मिट्टी की गुणवत्ता, ऑक्सीजन की उपलब्धता, अमोनिया का नियंत्रण, चूने का प्रयोग, गोबर का प्रयोग के बारे में विस्तृत जानकारी दी गई। साथ ही मछलियों में होने वाली बिमारी एवं उसके निदान के बारे में भी बताया गया। सभी उपस्थित मत्स्य कृषकों के सामने उनके द्वारा लाए गए पानी के नमूने का परीक्षण किया गया एवं तत्काल उसका निदान बताया गया। बीज संचयन पूर्व तालाब की तैयारी के बारे में भी बताया गया।

हिन्दुस्तान 25/8/25 पेज 4

'देश में कुपोषण से हर तीसरा बच्चा पीड़ित'

- खाद्य और पोषण सुरक्षा पर चिंतन मंथन शुरू
- तीन दिवसीय राष्ट्रीय प्रशिक्षण आयोजित

पूसा, निज संवाददाता। मैनेज, हैदराबाद के सहयोग से डॉ.राजेंद्र प्रसाद केंद्रीय कृषि विवि में तीन दिवसीय राष्ट्रीय स्तरीय प्रशिक्षण (वर्चुअल मोड) कार्यक्रम का आयोजन मंगलवार को किया गया। विषय था शुभारंभ भारत के संदर्भ में वैश्विक भूख सूचकांक को कम करने के लिए खाद्य एवं पोषण सुरक्षा।

कार्यक्रम की शुरूआत करते हुए डीन पीजीसीए डॉ. मयंक राय ने कहा कि भारत को दलहन और तेलहन उत्पादन में आत्मनर्भिर बनने की जरूरत है। जिससे विदेशों पर नर्भितरता कम हो सके। उन्होंने कहा कि जैव संवर्धित (बायो फोर्टीफाइड) फसलो के खाद्य सुरक्षा को बढ़ावा देने पर देश में कार्य चल रहा है। इसे जलवायु परिवर्तन के प्रभाव से भी कम किया जा सकता है।

पूसा विवि में वर्चुअल मोड में आयोजित प्रशिक्षण में चर्चा करते वैज्ञानिक। • हिन्दुस्तान

डीन डॉ.उषा सिंह ने आहार विविधता से पोषण सुरक्षा, पोषणयुक्त उत्पादों से कुपोषण को कम करने पर चर्चा की। डॉ. ऋतंभरा सिंह ने किसान उत्पादक संगठन (एफपीओ), मूल्य श्रृंखला और बाजार संपर्क से कुपोषण को कम करने पर ज्ञान साझा किया। केरल विवि की वैज्ञानिक डॉ. अपर्णा राधाकृष्णन, ने केरल मॉडल को अपनाकर खाद्य और पोषण सुरक्षा के लक्ष्य प्राप्त करने का सुझाव दिया। प्रशिक्षण में 21 राज्य, 68 संस्थानों के 214 प्रशिक्षणाथियों ने हस्सिा लिया। संचालन करते हुए विवि के वैज्ञानिक डॉ.सत्य प्रकाश ने किया।

डॉ. सुधानन्द प्रसाद लाल ने कहा कि भारत में 5 वर्ष से कम उम्र के 35.5 बच्चे कुपोषण के कारण अविकसित हैं। इसका मुख्य कारण पौष्टिक आहार की कमी है। इसे सुधारने के लिए गर्भवती महिलाओं और बच्चों को संतुलित आहार देना, 6 महीने तक केवल स्तनपान कराना, टीकाकरण, स्वच्छ पानी और स्वच्छता सुनश्चिति करना जरूरी है। वैज्ञानिक ने पोषण जागरूकता और आंगनवाड़ी व मिड-डे मील जैसे सरकारी योजनाओं को मजबूत करने पर बल दिया। धन्यवाद ज्ञापन वैज्ञानिक डॉ.सत्य प्रकाश ने किया।

देश को दलहन उत्पादन में आत्मनिर्भर बनाना जरूरी : डा राय

प्रतिनिधि,पूसा

डॉ. राजेंद्र प्रसाद केंद्रीय कृषि विश्वविद्यालय पूसा द्वारा मैनेज हैदराबाद के सहयोग से 3 दिवसीय राष्ट्रीय स्तरीय प्रशिक्षण (वर्चुअल मोड) कार्यक्रम का आयोजन भारत के संदर्भ में वैश्विक भूख सूचकांक को कम करने के लिए खाद्य एवं पोषण सुरक्षा विषय पर किया गया. शुभारंभ करते हुए कृषि स्नातकोत्तर महाविद्यालय के अधिष्ठाता एवं प्रसार शिक्षा निदेशक, डा. मयंक राय ने कहा कि समय आ चुका है कि भारत दलहन और तिलहन उत्पादन में भी आत्मनिर्भर बने. उन्होंने बल देते हुए कहा कि भारत द्वारा परीक्षण की जा रही जैव-संवर्धित बायो-फोर्टीफाइड फसलें किस प्रकार खाद्य सुरक्षा को बढ़ावा दे सकती है और जलवायु परिवर्तन के प्रभाव को भी कम कर सकती है. डॉ. उषा सिंह ने आहार विविधता के माध्यम से पोषण सुरक्षा प्राप्त करना एवं विश्वविद्यालय के कई पोषणयुक्त उत्पादों के माध्यम से कैसे कुपोषण को काम किया जा सकता है इस पर बल दिया. डॉ ऋतंभरा सिंह ने किसान उत्पादक संगठन (एफपीओ), मूल्य श्रृंखला और बाजार संपर्क द्वारा कुपोषण को कैसे काम किया जा सकता है पर विस्तार से चर्चा की. डॉ. अपर्णा राधाकृष्णन ने उर्ध्वाधर खेती और केरल मॉडल को अपनाकर खाद्य और पोषण सुरक्षा के लक्ष्य पर ज्ञान साझा किया. प्रशिक्षण कार्यक्रम में 21 राज्य, 68 विभिन्न संस्थानों के 214 प्रशिक्षणार्थी ने भाग लिये. डा. सुधानन्द प्रसाद लाल ने संचालन किया. धन्यवाद ज्ञापन डा. सत्य प्रकाश ने किया.

GLIMPSES OF THE MEDIA COVERAGE

Food and Nutrition Security to Mitigate Global Hunger ‘Index’ apropos India

Editors

Sudhanand Prasad Lal, Kumari Sushmita, Satya Prakash, Naresh Kethavath, & Veenita Kumari