Pan India Survey

FARMING ON THE EDGE

The Challenges of Small Farm-Holding Farmers Across India

Report prepared by

IIT Ropar - Technology and Innovation Foundation (iHub - AWaDH)
(DST NM-ICPS Technology Innovation Hub)

&

Office of Principal Scientific Adviser
to the Government of India

Mandeep Singh, Avinash Bhardwaj

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Organisation

The IIT Ropar Technology and Innovation Foundation (iHub - AWaDH), established under the National Mission on Interdisciplinary Cyber-Physical Systems (NM-ICPS) by the Ministry of Science and Technology, focuses on deep-tech innovations in agriculture and water. With a ₹110 crore grant from the Department of Science & Technology (DST) under NM-ICPS and additional funding from Startup India. iHub - AWaDH promotes sustainable agriculture through an extensive network of over 200 partners, including the VC community, government bodies, FPOs, and NGOs. It supports startups, research, and CPS skill development while being recognized as a leader in agri-tech. To revolutionize agriculture with CPS technologies, iHub - AWaDH is developing an Agri-Tech Consortium Platform

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We extend our sincere gratitude to the Office of the Principal Scientific Adviser to the Government of India for their insights in addressing agricultural and water management challenges. We also acknowledge the Indian Institute of Technology Ropar(IIT Ropar) and iHub - AWaDH for their pivotal role in advancing research, innovation, and technology in the agricultural sector. Under the leadership of Prof. Rajeev Ahuja, Director, IIT Ropar, the institute has emerged as a leading hub for technical education and research, fostering industry-academia collaboration and entrepreneurial growth. Additionally, Dr. Pushpendra P. Singh, Dean R&D, IIT Ropar & Project Director, iHub - AWaDH, has been instrumental in driving deep-tech innovations, supporting startups, and translating research in agriculture, water, and sustainability into real-world agricultural solutions. Additionally, we acknowledge the contributions of researchers, stakeholders, and farmers whose inputs have been instrumental in shaping this report.

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Acknowledgement

We extend our sincere and heartfelt gratitude to the Strategic Alliance Division, Office of the Principal Scientific Advisor (PSA), and the Department of Science and Technology (DST), Government of India, for their invaluable guidance and unwavering support throughout the planning and execution of this extensive nationwide survey of smallholder farmers. Their strategic vision and commitment to advancing agricultural research and policy development have been instrumental in shaping the scope and impact of this study. Their encouragement and facilitation have played a crucial role in ensuring the success of this initiative, and we deeply appreciate their continued efforts in fostering innovation and data-driven decision-making in the agricultural sector.

A special acknowledgment to Dr. Sapna Poti, Head of the Strategic Alliance Division, PSA Office, for her leadership and commitment to strengthening agricultural research and policy frameworks in India. Her contributions have significantly shaped this initiative, and we take great pride in recognizing her achievement in receiving the Swedish Leadership Award, alongside a distinguished professor from Uppsala Agriculture University. Their recognition underscores the global impact of collaborative efforts in agricultural innovation and sustainability, reinforcing the collective drive toward advancing smallholder farming solutions.

We acknowledge the Indian Institute of Technology Ropar (IIT Ropar) and iHub - AWaDH for their pivotal role in advancing research, innovation, and technology in the agricultural sector. Under the leadership of Prof. Rajeev Ahuja, Director, IIT Ropar, the institute has emerged as a leading hub for technical education and research, fostering industry-academia collaboration and entrepreneurial growth. Additionally, Dr. Pushpendra P. Singh, Dean R&D, IIT Ropar & Project Director, iHub - AWaDH, has been instrumental in driving deep-tech innovations, supporting startups, and translating research in agriculture, water, and sustainability into real-world agricultural solutions.

Our deepest appreciation is extended to the Krishi Vigyan Kendra's (KVKs) across 115 districts, whose dedicated involvement at the grassroots level was pivotal in gathering field data. The extensive network of KVKs, along with their dedicated field staff and subject-matter experts, ensured that this survey reached the most remote farming communities, capturing diverse agricultural realities across various regions. Their tireless commitment to agricultural extension services and knowledge dissemination has significantly contributed to the robustness and inclusivity of this report. Special mention to KVK Ropar, the Agriculture and Horticulture Department Punjab, and ATMA Punjab for their support while the physical survey was conducted.

We are immensely grateful to the numerous Farmer Producer Organizations (FPOs) and Farmer Producer Companies (FPCs) that actively facilitated direct engagement with farming communities. Their efforts in bridging the gap between researchers and farmers have been invaluable in ensuring the authenticity, depth, and comprehensiveness of the data collection process. Their deep understanding of local agricultural contexts, market dynamics, and the socio-economic conditions of smallholder farmers has played a vital role in enriching the insights derived from this study. Without their collaboration, the scale and depth of this survey would not have been achievable.

A special acknowledgment is due to the smallholder farmers who participated in this survey, generously sharing their experiences, challenges, and aspirations. Their willingness to contribute their time and insights despite their demanding schedules is a testament to their dedication to improving agricultural practices and livelihoods. Their candid responses have provided a wealth of knowledge that will serve as a foundation for shaping future agricultural policies, interventions, and innovations aimed at addressing their most pressing concerns.

We also take this opportunity to recognize the exceptional contributions of our research team members, field supervisors, and data analysts who worked diligently to ensure the quality, accuracy, and reliability of the survey findings. Their commitment to methodological rigor, data integrity, and thorough analysis has significantly enhanced the credibility and impact of this report. Their expertise, patience, and attention to detail in handling vast amounts of data have been critical in translating raw information into meaningful insights that can drive policy and decision-making.

Furthermore, we extend our gratitude to all other stakeholders and institutions, including academic bodies, policy think tanks, and agricultural research organizations, whose direct and indirect contributions have been instrumental in the successful completion of this comprehensive agricultural survey. Their support, whether through technical expertise, logistical assistance, or constructive feedback, has enriched this study and strengthened its overall impact.

Finally, we acknowledge the countless individuals behind the scenes who contributed in various ways to the execution of this survey. From field coordinators to administrative staff, their dedication and hard work have played a crucial role in bringing this initiative to fruition. Their collective efforts have enabled us to present a report that truly reflects the realities, needs, and aspirations of India's smallholder farmers.

Once again, we extend our sincere thanks to all contributors and farmers who have been part of this journey. It is through such collective efforts and collaborations that meaningful advancements in the agricultural sector can be achieved, paving the way for a more resilient and sustainable farming ecosystem.

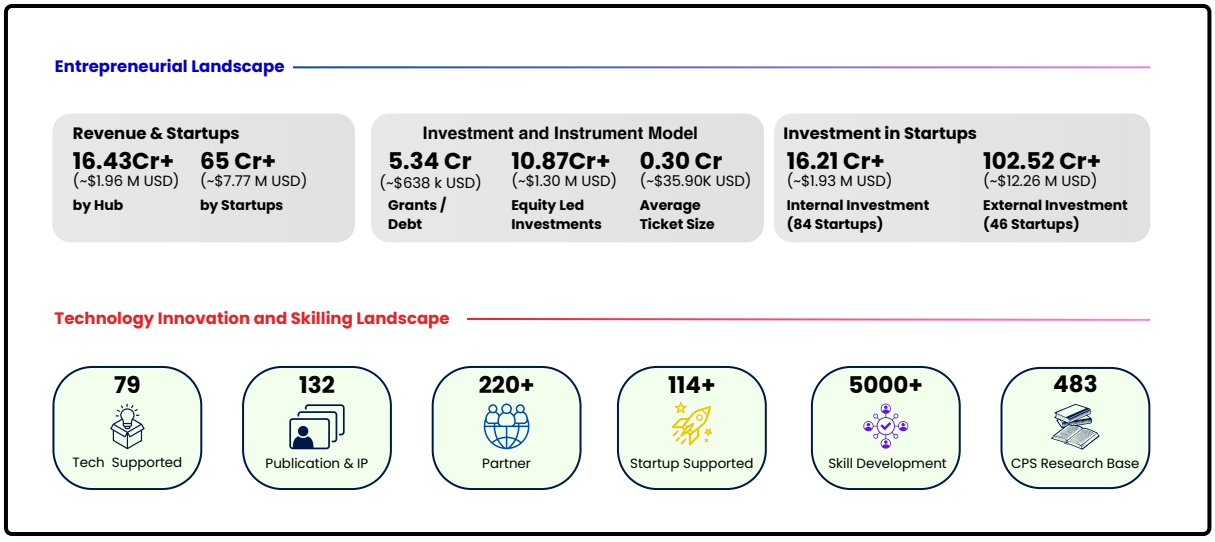
About AWaDH

IIT Ropar Technology and Innovation Foundation, also known as iHub-AWaDH, is a dedicated Agriculture and Water Technology Development Hub established at the Indian Institute of Technology Ropar by the Department of Science & Technology (DST), Government of India. This foundation operates under the National Mission on Interdisciplinary Cyber Physical Systems (NM-ICPS) and is a part of India's forward-thinking strategy to drive impactful advancements in agriculture, water technology, and related fields. Supported by an investment of ₹110 crore from DST and an additional ₹5 crore from Startup India, iHub-AWaDH is designed to foster a research ecosystem that merges innovation with practical solutions, directly addressing some of India's most pressing needs in sustainable agriculture and water management.

At its core, iHub-AWaDH is driven by the vision of creating an environment where agriculture is not only environmentally sustainable but also profitable, providing quality food for all while ensuring the preservation of biodiversity. Through this vision, iHub-AWaDH seeks to support deep-tech research ideas, incubate technology-driven startups, and foster a community of innovators and entrepreneurs who can drive this mission forward. The foundation plays a pivotal role in the research and development domains of Agriculture, Water, the Internet of Things (IoT), and Interdisciplinary Cyber Physical Systems (ICPS), and it actively nurtures startups through incubation, acceleration resources, and commercialization support. This support ecosystem promotes sustainability and is instrumental in transforming technological solutions into market-ready products that benefit both the environment and the economy.

The impact and achievements of iHub-AWaDH are considerable. Over the years, it has generated more than ₹16 crore in revenue, facilitated over ₹109 crore in investments for startups, and built a vibrant portfolio of 110+ startups valued at over ₹1200 crore. The foundation has developed and deployed more than 70 market-ready technologies and established over 180 intellectual assets, including patents and proprietary technologies. Additionally, iHub-AWaDH has built a research base with over 480 CPS researchers and created employment opportunities for more than 800 individuals while training over 3,000 professionals in relevant fields. This effort has also nurtured a generation of future leaders, with 5,000+ individuals being developed in cyber-physical systems (CPS).

iHub-AWaDH's dedicated team of over 200 members continues to work diligently to advance its mission, create cutting-edge solutions, and strengthen India's agricultural and water technology sectors. With its strong support from the DST and the Government of India, the foundation is set to remain a cornerstone of agricultural sustainability and technological growth in the country. Through fostering research, nurturing startups, and supporting innovations, iHub-AWaDH is building a legacy that aligns with the nation's goals for a more sustainable and prosperous future in agriculture and water management.



Foreword

Agriculture remains the foundation of India's economic and social fabric, with smallholder farmers playing a pivotal role in ensuring food security and rural livelihoods. However, these farmers continue to face multifaceted challenges, including limited access to quality inputs, technology, and market linkages, exacerbated by climate change and resource constraints. To address these issues, it is crucial to integrate modern scientific advancements with grassroots wisdom, ensuring that innovations reach the very core of India's agrarian communities.

As a Member of Parliament and a proponent of sustainable rural development, I believe that technology-driven policy interventions must prioritize inclusivity, affordability, and accessibility. The Indian Institute of Technology Ropar (IIT Ropar), through iHub - AWaDH, has been a front-runner in leveraging deep-tech solutions for agriculture and water resource management. Their pioneering work in agri-tech innovation, startup incubation, and stakeholder collaboration aligns with the broader vision of Atmanirbhar Bharat, empowering farmers with cutting-edge yet practical solutions.

This report, jointly prepared by the IIT Ropar Technology and Innovation Foundation (iHub - AWaDH) and the Office of the Principal Scientific Adviser to the Government of India, presents a road-map to address the pressing challenges faced by Indian farmers. Drawing from extensive field studies, expert consultations, and technology-driven insights, it offers a framework for scalable solutions, policy enhancements, and public-private partnerships.

Through initiatives like "Public Policy for India People," I have actively worked toward fostering a research-driven approach to policy making, ensuring that India's farmers receive the support they need to thrive in a changing economic and environmental landscape. I strongly believe that the collaboration of research institutions, policymakers, and industry leaders will pave the way for a resilient and sustainable agricultural sector.

As India advances towards a digitally integrated and ecologically sustainable future, this report stands as a testament to the commitment of IIT Ropar and iHub - AWaDH in driving innovation for the betterment of our farmers and rural communities. I look forward to seeing the transformative impact of these initiatives in shaping the future of Indian agriculture.

Dr. Pradip Kumar Varma
Member of Parliament, Rajya Sabha

Foreword

Agriculture remains the backbone of India's economy, with smallholder farmers constituting the majority of the farming population. However, these farmers face numerous challenges, ranging from limited access to quality inputs and technology to unpredictable climate conditions and market uncertainties. In an era where digital transformation, precision agriculture, and sustainable farming practices are reshaping the agricultural landscape, it is imperative to bridge the gap between technological advancements and grassroots-level adoption.

The Indian Institute of Technology Ropar (IIT Ropar) has been at the forefront of innovation and research since its inception in 2008, rapidly establishing itself as a center of excellence in technical education. Under the aegis of iHub - AWaDH, established in 2020, and has played a pivotal role in advancing agriculture and water technology, leveraging cutting-edge research, industry collaborations, and startup incubation. Through strategic partnerships with academic institutions, government bodies, and corporate stakeholders, iHub - AWaDH has fostered deep-tech innovations that are driving sustainable development in agriculture and rural ecosystems.

This report, prepared by the IIT Ropar Technology and Innovation Foundation (iHub - AWaDH) in collaboration with the Office of the Principal Scientific Adviser to the Government of India, presents a comprehensive analysis of the challenges and opportunities for smallholder farmers across India. With insights gathered from extensive field studies, stakeholder consultations, and technological assessments, this document serves as a road map for policy interventions, research-driven solutions, and scalable innovations to empower smallholders.

At iHub - AWaDH, they are committed to bridging the gap between research and real-world applications by providing the necessary resources, mentorship, and market access to startups and technology innovators. Through initiatives such as SAMRIDHI, ASAP Accelerator, and CPS Innovation Labs, they have supported 100+ deep-tech startups and spearheaded 200+ R&D projects that address critical challenges in agriculture, water management, and rural livelihoods.

As India progresses towards a technology-driven, inclusive, and sustainable agricultural sector, IIT Ropar and iHub - AWaDH remain steadfast in their mission to create impactful solutions that benefit farmers, entrepreneurs, and the broader ecosystem. This report reflects our continued efforts to drive innovation, promote sustainability, and shape the future of Indian agriculture through collaborative research, technological interventions, and strategic policy recommendations.

Sapna Poti (Mar 17, 2025 09:25 GMT+5.5)

Dr. Sapna Poti
Director, Strategic Alliances

Office of the Principal Scientific Adviser to the Government of India

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During the ground-level survey, we had insightful and in-depth conversations with farmers from Moga District, Punjab, gaining valuable perspectives on their agricultural practices, challenges, and aspirations.

Executive Summary

This report presents a comprehensive analysis of a nationwide survey aimed at understanding the challenges, constraints, and aspirations of small farm-holding farmers across India. Conducted across 115 districts and incorporating data from over 3.4 million farmers—including 1.5 million smallholders—this extensive study sheds light on critical barriers limiting agricultural productivity, financial stability, and the adoption of advanced farming technologies.

The findings underscore the multi-dimensional nature of these challenges, ranging from limited access to quality inputs and credit facilities to inefficient market linkages and the slow adoption of agricultural technology. While 52% of farmers reported having moderate access to essential resources like seeds and fertilizers, 47% identified credit availability as a persistent challenge due to bureaucratic loan processes and complex eligibility criteria. The need for direct market access emerged as a high priority, with 76% of farmers emphasizing that limited market opportunities hinder their ability to obtain fair prices and maximize profitability. In parallel, 60% expressed an urgent requirement for modern farming machinery, recognizing the role of mechanization in mitigating labor shortages and enhancing operational efficiency.

A closer examination of irrigation practices further highlights the need for modernization in water resource management. The survey found that 62.5% of farmers rely predominantly on flood irrigation, a method that, while widely used, contributes to inefficient water use and soil degradation.

Financial Stability and Income Disparities: The Struggle for Economic Resilience

Perhaps one of the most concerning revelations from the survey is the financial vulnerability of smallholders. A mere 12.5% of farmers reported an income increase exceeding 50% relative to operational costs, highlighting widespread difficulties in achieving financial resilience.

The data further reveals that:

- 76.3% of smallholders struggle with financial constraints, emphasizing the need for innovative credit solutions, such as digital lending platforms, microfinance models, and blockchain-based financial services that reduce reliance on traditional, often inaccessible, banking mechanisms.
- 75.6% face market-related difficulties, reinforcing the necessity of strengthening market linkages through farmer-producer organizations (FPOs), digital agribusiness platforms, and policy-driven procurement initiatives. Labour shortages continue to hinder efficiency, necessitating the integration of AI-powered automation, robotics, and smart mechanization to optimize farm operations and reduce dependency on manual labor.

Bridging the Technology Gap: A Pathway to Transformation

The survey findings expose a stark gap between the availability of cutting-edge agricultural technologies and their effective implementation at the grassroots level. Addressing this challenge requires targeted technology-mapping initiatives that directly connect farmers with relevant innovations developed by agritech startups, research institutions, and government-backed programs. One such initiative making substantial strides in this domain is the National Mission on Interdisciplinary Cyber-Physical Systems (NMICPS). Under this mission, Technology Innovation Hubs (TIHs)—such as AWaDH at IIT Ropar—are playing a transformative role in developing and deploying cyber-physical technologies tailored to agriculture.

AWaDH is spearheading the development of AI-driven soil monitoring systems, IoT-enabled smart irrigation models, and digital platforms for real-time crop advisory. These innovations are designed to enhance efficiency, reduce input costs, and minimize environmental risks, ensuring that smallholders can optimize productivity while maintaining sustainability. However, technology alone cannot drive change—its successful integration into smallholder farming depends on collaborative efforts between farmers, policymakers, financial institutions, and industry stakeholders.

As India moves forward in its agricultural revolution, initiatives like AWaDH and the broader NMICPS mission will continue to serve as catalysts for change, ensuring that smallholders are not left behind but instead become key players in shaping the future of Indian agriculture. By bridging knowledge gaps, driving digital inclusion, and enabling smallholders with cutting-edge innovations, the Indian agricultural landscape can achieve sustainable prosperity for generations to come.

Climate Change Hit Small Farmers in Five Years

TA report by the Forum of Enterprises for Equitable Development (FEED) indicates that over 60% of marginal farmers have experienced crop and yield losses due to climate change-induced extreme weather events in the past five years.

Source: *The New Indian Express,*

1-Background

The landscape of smallholder agriculture in **India** presents a complex mix of strengths and challenges, rooted in the country's historical and socio-economic fabric. India is part of a broader trend across the Asia and Pacific region, which has some of the smallest landholding sizes globally. The average landholding in this region is only about one hectare—significantly lower than the global average of 5.5 hectares—highlighting the structural challenges that **smallholder farmers** face (World Programme of Census of Agriculture, FAO). This **limited land size** restricts the ability of small farm-holding farmers to produce surpluses, often resulting in economic vulnerability and financial insecurity. In many cases, their small land holdings are insufficient to generate a substantial income that would allow them to save or invest in farm improvements. As a result, smallholders are often caught in a cycle of low productivity and **constrained** economic growth, making it challenging to improve their livelihoods sustainably.

According to the 10th agriculture census 2015-16, Small and marginal farmers with less than two hectares of land account for just over 86% of all farmers in India, but own just about 47% of the crop area. Overall, the census has shown that while Indian farms became **more fragmented** between 2010-11 and 2015-16, holdings continued to be **inequitably** distributed. During this period the proportion of small and marginal farmers grew from 84.9% to 86.2% (a growth of about 9 million), while the total number of operational holdings grew from 138 million to 146 million. Further, these 126 million farmers owned, on average, 0.6 hectares holding each, which is not enough to produce surpluses which can financially sustain their families, explaining the rising distress in Indian agriculture. "The rise in the number of small and marginal farmers signifies that the rest of the economy is unable to absorb the surplus. India has to live with its small-sized farms in the next two decades and the way out is to provide them access to the best technology and markets, the way China did it," according to Ashok Gulati, agriculture chair professor at the Indian Council for Research in International Economic Relations. Professor Gulati further adds that small farms can be **economically** viable through diversification into high-value crops and **massive capital investments** in value chains. Admittedly, the existence of a large number of small and marginal farmers means it is challenging for the government's extension arms to reach them with new technology and farm support schemes. However, the Government of India has met this challenge head-on by realigning its interventions from a production-centric approach to farmers' **income-centric** initiatives, with a focus on better and new technological solutions.

The situation is quite **vulnerable** for the small and marginal farmers (having less than 2 ha of land), depicting hardships in their sustenance solely on agriculture. Moreover, farming is increasingly becoming **unremunerative** on small land holdings due to high cost of inputs, variability in prices and temperature, and yield risk due to recurrent floods and famines. The small landholders are dominant in **low per capita income** states viz. Jharkhand, Bihar, Odisha, West Bengal, and Uttar Pradesh, earning a much higher share of income from wages and livestock activities.

The farmers are categorized on the basis of their landholdings into five distinct classes: Marginal, Small, Semi-Medium, Medium, and Large. Marginal landholdings are those below 1.00 hectare, while Small landholdings range from 1.00 to 2.00 hectares. Semi-Medium landholdings cover 2.00 to 4.00 hectares, and Medium landholdings span 4.00 to 10.00 hectares. Large landholdings are those that are 10.00 hectares and above.

In the "India Rural Development Report 2012-13" prepared by the IDFC Rural Development Network, it has been observed that Small farms are more efficient, especially in cultivating **labor-intensive** crops or tending livestock, but land holdings are too small to generate sufficient household income.
One of the primary obstacles facing India's small farm-holding farmers is restricted access to critical resources. With limited financial means and small plot sizes, smallholders often struggle to invest in productivity-enhancing resources such as quality seeds, fertilizers, and irrigation systems. Credit access is another major barrier, as smallholders face difficulties **securing loans** due to limited collateral and a **complex approval** process. This lack of financial support limits their capacity to adopt advanced farming practices or invest in new technologies that could increase their yield and profitability.

The adoption of modern farming techniques remains low among smallholders, many of whom rely on traditional, labor-intensive methods passed down through generations. These methods, while sustainable in certain respects, limit productivity and may not meet the demands of a growing population or **changing climate** conditions. For example, smallholders often rely on rain-fed agriculture and basic irrigation methods, with little access to mechanized tools or water-efficient technologies. This dependence on traditional practices is further complicated by high input costs, volatile market prices, and limited access to extension services that could inform them of improved agricultural practices and crop varieties better suited to their local conditions.

Market access is another critical issue for smallholders, who generally have **limited bargaining power** and are vulnerable to market fluctuations. Unlike larger farmers, smallholders typically lack direct access to markets and are often forced to sell their produce to intermediaries at lower prices. This situation restricts their income potential and increases economic vulnerability, as they are unable to negotiate fair prices for their produce. Additionally, with little access to cold storage or transportation infrastructure, smallholders face significant **post-harvest losses**, further reducing their income.

Market volatility and low negotiating power mean that even when smallholders achieve high yields, they may not benefit financially. This volatility makes income stability elusive, pushing many smallholders to seek **supplemental employment** or cut back on essential inputs. Smallholders' economic uncertainty is further **exacerbated** by global and local disruptions, including shifts in commodity prices, policy changes, and extreme weather events. These challenges underline the need for policies that strengthen market linkages, build resilient value chains, and provide reliable avenues for smallholders to sell their produce at fair prices.

Rural demographic changes are **compounding** these challenges. The lack of economic incentives and the low profitability of small-scale farming are pushing many young people to migrate to urban areas in search of better opportunities. This shift has not only led to a decline in the availability of labour in rural areas but has also resulted in a **demographic shift** within the agricultural workforce. As young people migrate, agriculture is increasingly managed by older generations and women, who take on multiple roles as cultivators, entrepreneurs, and laborer's. This **"feminization"** of agriculture, while empowering for women, introduces unique challenges related to resource access, capacity building, and decision-making roles.

The loss of youth from rural areas disrupts the **intergenerational transfer** of traditional knowledge and farming skills, which are crucial for the long-term sustainability of smallholder agriculture. Moreover, with rural youth seeking employment outside of agriculture, there is less investment in small-scale farming and fewer innovations adopted within **rural communities**. The result is a cycle of reduced productivity, economic stagnation, and a growing divide between urban and rural livelihoods. This demographic shift highlights the importance of **revitalizing** rural economies, particularly through skill development, infrastructure investment, and access to diversified income opportunities that can make farming more appealing and profitable for younger generations.

Therefore, against the backdrop of these **multidimensional challenges**, this study attempts to assess the specific problems of small farm-holding farmers through an in-depth Pan-India survey and through an on-ground survey conducted in Punjab. The objective of this study is to capture the **heterogeneity** in experience, resource limitation, and unique needs of the smallholders by gathering comprehensive insights from farmers across diverse regions. This also would bring into focus the structural challenges as a whole prevalent in this sector, and regional perspectives could be presented, particularly from Punjab, in view of varying agricultural practices and challenges due to the local weather conditions and cropping pattern. To have **actionable insights** through this survey, we will revise some policy recommendations and **targeted interventions** that would help the smallholders overcome the barriers to productivity, sustainability, and economic stability. In addition to evaluating the challenges faced by small farm holding farmers, this study advocates for technology mapping between R&D institutions, startups, and the agricultural sector.

With **innovative solutions** that are crucial for overcoming the limitations on smallholders' potential, this study aims at bridging the gap between farmers' needs and technological developments being made across India. This study links these needs via a Pan-India survey and an on-ground in-depth survey in Punjab with relevant R&D outputs, emerging technologies, and scalable solutions offered by startups. The approach of technology matchmaking involves aligning the technological capabilities of **institutions** and **innovators** with the unique challenges identified in the surveys.

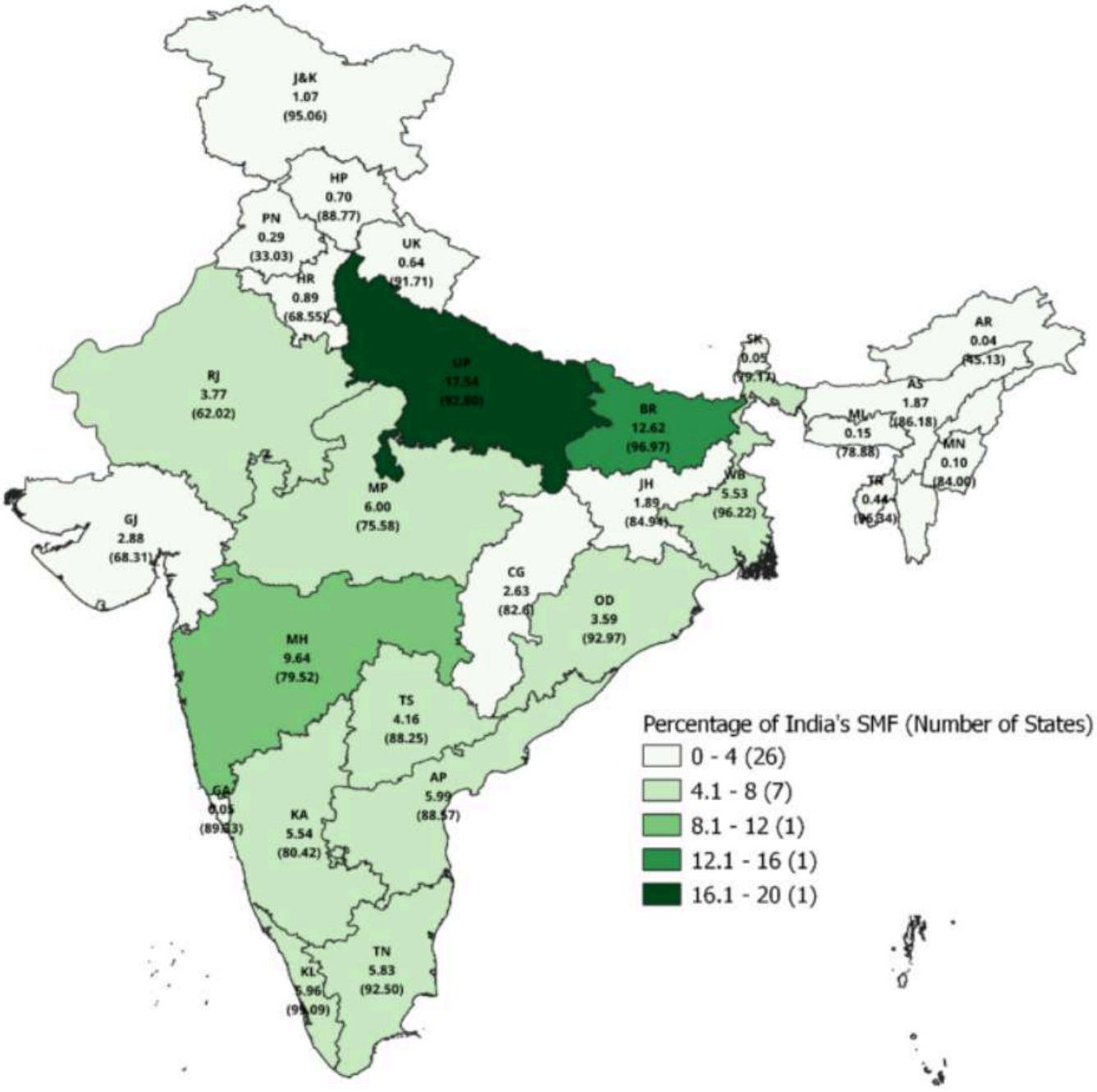
For instance, precision agriculture solutions, irrigation systems at affordable cost, **mechanization**, and digital platforms providing access to markets can provide functional support to smallholders by optimizing resource use, increasing yield, and stabilizing income. This matchmaking is supposed to **catalyze** partnerships that will enable technology adoption at the **grassroots level**, ensuring farmers have appropriate, scalable tools for their needs. **Coupled** with integrating these technological solutions into farmers' traditional practices and specific regional conditions, this study develops an imperative for a more resilient, productive, and economically viable future pertaining to India's small-farm-holding farmers.

1.1 Trends in Indian SMF's Landholdings

India's Agricultural Census, conducted every ten years since 1970-71, reveals **significant** trends in landholdings. Over time, the number of landholdings in India has grown substantially, increasing from about 71 million in 1970-71 to 146 million in 2015-16. Concurrently, the average size of these landholdings has been **shrinking**, decreasing from 2.3 hectares in 1970-71 to 1.1 hectares in 2015-16.(Agriculture Census: 1970-71 and 2015-16) Additionally, a significant portion of India's agricultural land is now operated by small and marginal farmers (SMF). In 2015-16, about 47.3 percent of operational land was held by SMFs, up from approximately 21 percent in 1970-71

1.2 Distribution of Small Farmers State Wise:

About 50 percent of India's small and marginal farmers (SMF) reside in five states: Uttar Pradesh (18 percent), Bihar (13 percent), Maharashtra (10 percent), and Madhya Pradesh and Andhra Pradesh (each with 6 percent), according to the Agriculture Census 2015-16. The concentration of SMFs is depicted in Figure 1, where darker green indicates a higher concentration of SMFs within a state. In contrast, India's northern and northeastern states generally have larger landholdings and/or a lower number of farmers.



(Source :Agriculture Census 2015-16)

Statewise Distribution of Small Farm Holding Farmers in India

2. Objectives of the Study

The survey aims to address the multifaceted challenges faced by smallholding farmers in India. Specifically, it focuses on identifying critical gaps in resources, understanding socio-economic constraints, exploring gender-specific issues, and highlighting technology needs. The survey seeks to connect these insights with the technological solutions available on platforms like KisanMitra, Manthan, RuTAG, and AWaDH IIT Ropar.

Research Objectives	Identified Gaps/Challenges	Research Questions
Assessing Resource Accessibility	Limited access to essential resources such as land, water, quality seeds, and financial credit for small farmers.	How accessible are fundamental resources like land, water, seeds, and credit for small farmers, and what barriers limit this access?
Identifying Primary Challenges	Productivity and resilience of small farms are impacted by several constraints, including environmental and economic factors.	What are the core challenges faced by small farmers that affect their productivity and resilience?
Exploring Gender-Specific Issues	Female farmers face unique issues, including limited access to resources, training, and market linkages.	What are the specific challenges encountered by female farmers, and how can support mechanisms be tailored to address these needs?
Determining Technological Needs	Technology gaps exist that limit efficiency and scalability in smallholder farming practices.	What are the technological needs and existing gaps that smallholders face in adopting efficient farming practices?
Mapping Technological Solutions	Disconnection between available technological solutions and specific smallholder needs.	How can available technologies, such as those from KisanMitra and other platforms, be effectively matched to address identified challenges?

Author's Analysis :

Through this approach, the survey aims to create a comprehensive picture of the challenges and map over 1500 technologies to address these issues effectively.

Indian Farmers Carry on Burning Stubble Despite Cost to Health

Despite the known health risks and environmental impact, many Indian farmers continue the practice of stubble burning due to limited alternatives for crop residue management.

Source: *The Print*

2.1 Purpose of the Study

The study is focused on small and marginal farmers in India, a group that constitutes a majority in the agricultural sector but faces extreme **socio-economic** vulnerabilities. Marginal farmers encounter issues such as:

- Soil and Water Management Challenges: **Limited access** to fertile soil and dependable irrigation resources significantly impact crop yield.
- Financial Constraints: Difficulty in securing affordable credit and reliance on informal loans lead to high **financial stress**.
- Technological Barriers: Limited exposure to advanced farming technologies and lack of **technical support** constrain productivity.
- Market Access Challenges: Restricted access to Minimum Support Price (MSP), private markets, and government support limits income stability.

The cumulative effect of these challenges results in low, unstable incomes, increased livelihood risks, and gradual migration out of agriculture to precarious employment. For **marginal farmers**, a comprehensive support system incorporating accessible resources, technology, and fair market access is essential for sustainable livelihoods.

Key Areas of Focus:

- Highlighting Farmer Constraints: The study explores the depth of economic, social, and **logistical challenges** faced by marginal farmers.
- Examining Technological Gaps: By evaluating the current state of **technology adoption**, the study identifies key areas where technological solutions could offer support.
- Promoting Technology-Driven Solutions: The findings aim to bridge the gap between farmer needs and available technological innovations, facilitating adoption and support for small farmers.

Roundtable discussion with policy makers and experts on integration of technology with agriculture

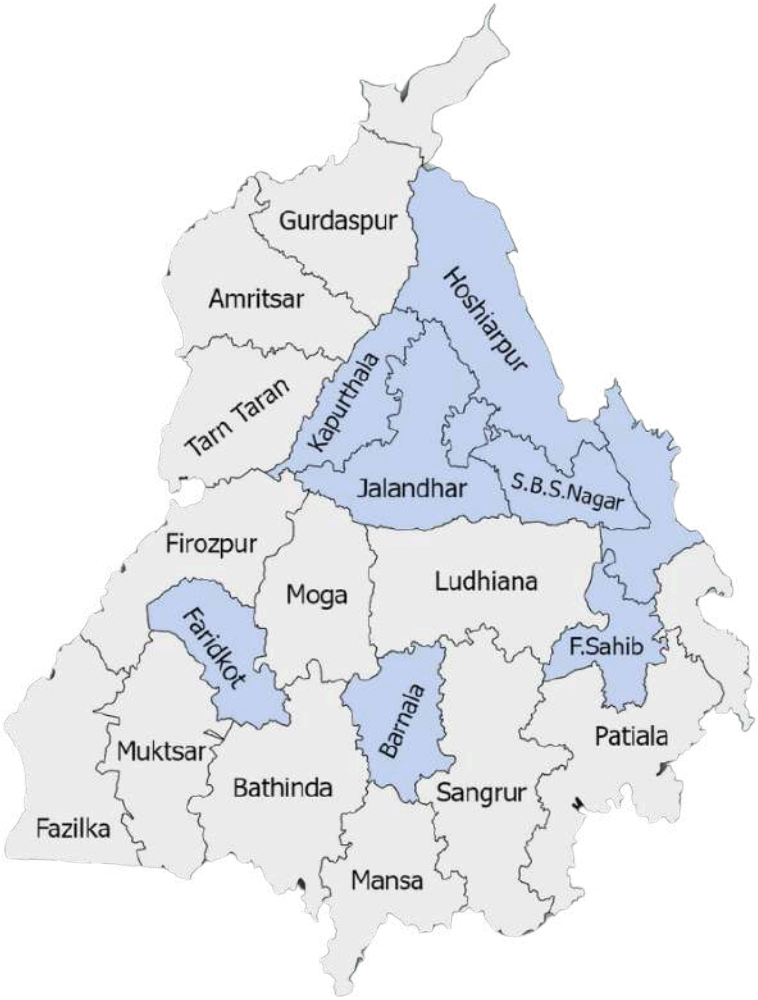
3. Methodology

3.1 Survey Design: Sample Size, Regions, and Target Respondents

The survey for this study was structured to capture a representative understanding of the challenges faced by smallholding farmers across India, with a focused, in-depth analysis in Punjab. Through a combination of convenience-based and stratified sampling, the study ensured broad yet contextually relevant insights into the agricultural practices, resource accessibility, technological needs, and gender-specific issues affecting small farm-holders.

3.1.1 Punjab Data Collection Approach

In Punjab, we implemented a convenience-based sampling method to streamline logistics while ensuring coverage of key agricultural regions. The study focused on districts within close proximity to **Rupnagar**, facilitating practical data collection from areas where smallholding farming is predominant. A total of **8 districts** were selected, including **Jalandhar**, **Kapurthala**, **Hoshiarpur**, **SBS Nagar**, **Rupnagar**, **Fatehgarh Sahib**, **Barnala**, and **Faridkot**, covering **20 tehsils** and **70 villages**. This sampling design enabled a targeted collection of responses that reflects the demographic and geographic distribution of smallholder farmers in Punjab.
The offline data collection in Punjab included 210 farmers as respondents, selected from various villages within the sampled districts. The selection process was structured to account for diversity in village size and landholding categories, mirroring Punjab's broader farming population characteristics. This setup enabled us to capture detailed responses on the localized challenges of Punjab's smallholders, particularly related to resource accessibility, technology adoption, and socio-economic factors. By focusing on nearby districts, the survey also allowed for in-person engagement, which improved the depth and accuracy of responses, especially for complex or nuanced issues that are best understood through direct interaction.

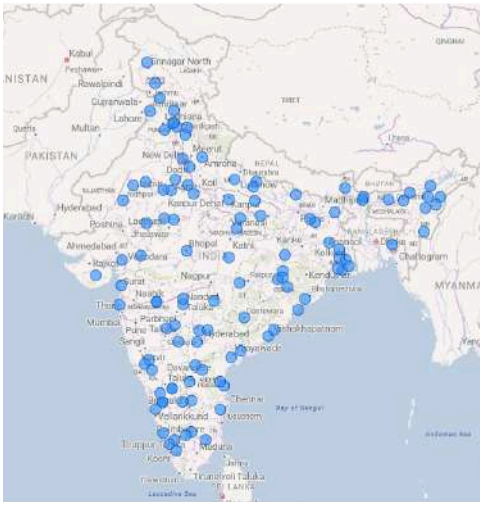


District wise map of Punjab with highlighted districts are surveyed.

3.1.2 Pan-India Data Collection Approach

To expand the study's scope beyond Punjab and capture insights applicable to smallholding farmers across different states and agricultural contexts in India, we employed an **online survey** with a **stratified sampling approach**. The national sample design aimed to ensure representation from various agricultural zones, cropping patterns, and farming systems, reflecting the diverse challenges and needs of smallholders across India. For national-level data, we partnered with key agricultural organisations, including **Krishi Vigyan Kendra's (KVKs)**, **Farmers Producer Organizations (FPOs)**, and **Farmers Producer Companies (FPCs)**, leveraging their networks to reach farmers in multiple states.

The online survey facilitated collaboration with 137 stakeholder organisations representing approximately **3.4 million farmers**. The sample included responses from 46 KVKs, 21 FPOs, and 69 FPCs, ensuring a balanced and comprehensive dataset. FPO data was sourced from the **Small Farmers' Agribusiness Consortium (SFAC)** website, providing reliable and up-to-date information on farmer demographics and organisational affiliations. By using stratified sampling, the study maintained proportional representation across states and regions, thereby achieving a diverse and inclusive sample of India's smallholding farmer population. This approach allowed us to investigate regional variations in technology needs, resource constraints, and operational challenges.



Sample Characteristics

Tools Used

The data collection process for this study was carefully structured to gather comprehensive, reliable insights from smallholding farmers across India, with a focused regional survey in Punjab. The objective was to understand the challenges, needs, and potential solutions for this critical segment of the agricultural population, through both in-person interactions and online surveys. Data collection was conducted over a **three-month period** from January to March 2024, allowing sufficient time to capture **seasonal variations** and address logistical challenges.

3.2.1 Questionnaire Design

We designed a structured questionnaire to capture insights into the challenges and technological needs of smallholding farmers, specifically addressing crop choices, resource accessibility, and technology adoption. The survey instrument included sections on **demographics**, crop management, **technology usage,** market access, financial support, and **awareness of government schemes**. Questions also focused on farmers' preferences for irrigation and pest management techniques, the extent of technology and machinery use, and familiarity with precision agriculture practices. Additionally, gender-specific challenges and perceptions on sustainable practices were examined.

The **Pan-India** online survey questionnaire aimed to collect broad insights, while the Punjab onsite survey focused on region-specific challenges and organisational support for farmers. The online questionnaire was designed to reach diverse farmer demographics across India and included sections on market access, financial needs, and training. For the onsite survey in Punjab, the questionnaire was adapted to gather detailed data on **community-level challenges**, with additional questions addressing women's representation, organisational support, and crop residue management.

The initial draft of both questionnaires was developed after an extensive review of existing literature on smallholding farmers, technology adoption, and rural agricultural challenges. Feedback was collected from experts at **IIT Ropar** and **agricultural extension officers**, leading to significant revisions. For the Punjab-specific survey, the questionnaire was **translated** into Punjabi and piloted in non-sampled villages across Ludhiana, Sangrur, Patiala, and Rupnagar districts. Insights from these pilot tests were incorporated into the final version, ensuring clarity and relevance for the target respondents.

3.2.2 Punjab Data Collection

For Punjab, data was collected through on-site, in-person visits to specific villages and tehsils across twelve districts, where surveyors interacted directly with farmers in their fields. This field-based approach provided a more nuanced understanding of the farmers' challenges and practices, allowing **surveyors** to observe field conditions, equipment used, and other contextual factors that might influence farming decisions. By physically visiting 20 tehsils and 70 villages in Punjab, surveyors engaged with farmers in their natural environment, making it easier for respondents to share authentic insights and discuss complex issues in detail.

The in-person survey in Punjab was conducted using a structured questionnaire loaded on an online tool, SurveyMonkey, which enabled surveyors to quickly capture responses digitally while in the field. This tool also allowed for **real-time data entry,** reducing potential errors and ensuring data consistency across different surveyors. The questionnaire covered a range of topics, including access to resources (such as water, seeds, and credit), technology needs, productivity challenges, and specific gender-related issues faced by female farmers. By adopting a face-to-face data collection strategy, the team was able to gather rich qualitative data, which provided context to the quantitative responses, offering a deeper understanding of the on-ground realities smallholding farmers face.

3.2.3 Pan-India Data Collection

To extend the study's reach beyond Punjab and ensure national representation, a pan-India survey was conducted through online channels, targeting a broader network of smallholding farmers across multiple states. Given the logistical and geographic constraints of in-person visits at a national scale, the survey relied on a stratified sampling approach and digital distribution. A structured survey form was created using **SurveyMonkey**, and the link to the survey was distributed to key agricultural stakeholders, including Farmers Producer Organizations (FPOs), Farmers Producer Companies (FPCs), and Krishi Vigyan Kendra's (KVKs), through email and direct outreach. This approach facilitated the collection of responses from a large, diverse pool of smallholding farmers, covering various regions, farming practices, and socio-economic conditions.

The survey form was shared with 137 stakeholder organisations (46 KVKs, 21 FPOs, and 69 FPCs), representing a network of around 3.4 million farmers across India. FPO and FPC data were sourced from the **Small Farmers' Agribusiness Consortium (SFAC)** website, which ensured that the sample was drawn from credible and representative farmer networks. By collaborating with KVKs, FPOs, and FPCs, the study was able to leverage the existing trust and engagement between these organisations and farmers, increasing the likelihood of participation and accurate responses. The survey link was accompanied by explanatory emails, and follow-up calls were conducted where necessary to encourage responses and clarify any questions respondents might have had about the survey content.

Some photographs of farmer's interaction during the survey

3.2.4 Survey Duration and Tools

The survey was open for responses from January to March 2024, allowing enough time to capture data from various regions and address potential delays in response collection due to agricultural seasons and other constraints. SurveyMonkey served as the primary data collection tool for both the **in-person** and **online surveys**. This tool was chosen for its user-friendly interface, **real-time data capture** capabilities, and secure storage, ensuring that sensitive information remained protected. SurveyMonkey's features enabled easy management and tracking of responses, which was particularly useful given the large sample size and the need to maintain data integrity.

By using SurveyMonkey, the team could also monitor response rates in real-time and make adjustments to the outreach strategy if needed. For example, if response rates were low in certain regions, additional reminders were sent, or local partners were asked to encourage participation. The digital tool also allowed for **quick data analysis** and preliminary insights, which informed any necessary adjustments in field protocols or questions to ensure that the study captured the most relevant information. For data cleaning, organization, and preliminary analysis, **Microsoft Excel (Advanced Excel), Power BI**, and **Looker Studio** were used. These tools enabled effective data visualization, quick error-checking, and a structured process for cleaning and refining the collected data, providing accurate insights for subsequent analysis.

3.2.5 Challenges and Limitations

While the data collection process was successful overall, certain challenges and limitations were encountered. In Punjab, **weather conditions and farmers' availability influenced survey schedules, as many farmers were occupied with fieldwork during peak hours.** Additionally, surveyors sometimes had to communicate in local dialects to ensure accurate understanding.

For the pan-India survey, the reliance on stakeholder-provided data introduced certain limitations. As the **data was gathered through stakeholders (KVKs, FPOs, and FPCs) rather than directly from individual farmers, the authenticity and accuracy of the responses may vary**, reflecting the perspectives of the organizations rather than the farmers themselves. This approach meant that the collected **data was representative of stakeholder inputs rather than direct farmer feedback**, potentially introducing bias or varying degrees of accuracy in the responses. This limitation was taken into account during data analysis to provide a realistic interpretation of the results.

Some photographs of farmer's interaction during the survey

Why Small Farmers Remain Anxious About the Monsoon ?

***C**oncerns of small farmers regarding monsoon patterns, emphasizing the critical role of timely and adequate rainfall in agricultural productivity and the challenges posed by unpredictable weather.*

***Source:** The Times of India*

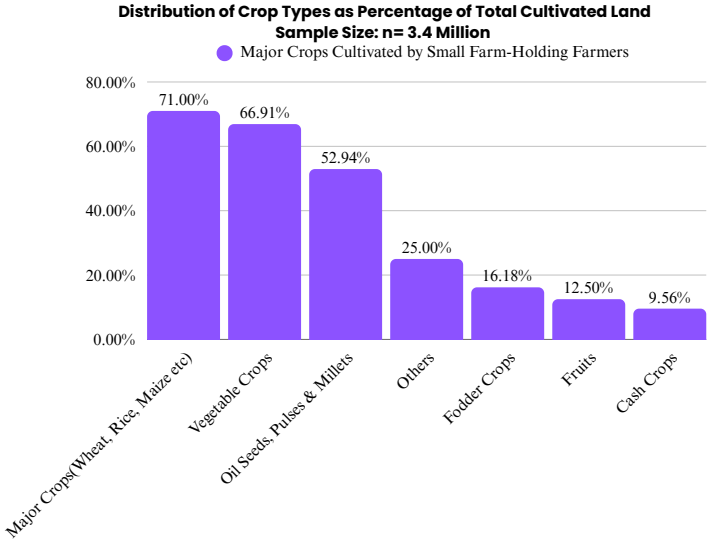
4- Key findings

4.1 How accessible are essential resources for small farmers?

4.1.1 Major crops cultivated in India

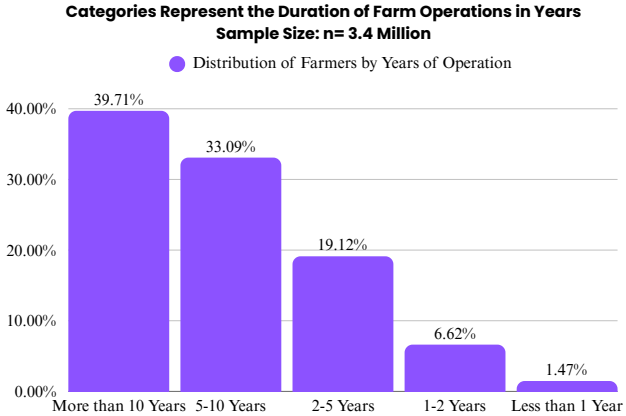
India's agricultural sector is characterised by a diverse array of major crops that are integral to the country's economy and food security. The primary food crops include rice and wheat, which serve as staple foods for the vast majority of the population. Rice, predominantly cultivated in states like West Bengal, Punjab, and Uttar Pradesh, thrives in the monsoon season, while wheat is primarily grown in the Rabi season across northern India. Other essential food crops include pulses, millets, and coarse cereals, which contribute to dietary diversity and nutrition. In addition to food crops, India is a leading producer of several cash crops, such as cotton, sugarcane, and tea, which are vital for export and industrial use. The cultivation of these crops is influenced by regional climatic conditions, soil types, and agricultural practices, showcasing the country's rich agricultural heritage

The graph below displays the distribution of crop types as a percentage of total cultivated land, with a sample size of 3.4 million small farm-holding farmers. The most popular crops are major crops like wheat, rice, and maize, accounting for 72.06% of cultivated land. Following closely are vegetable crops at 66.91%. Oil seeds, pulses, and millets take up 52.94% of the land, while other crops contribute 25.00%. Fodder crops occupy 16.18%, fruits 12.50%, and cash crops 9.56% of the total cultivated land. This data suggests that small farm-holding farmers in the region primarily focus on producing staple foods like wheat, rice, and vegetables, with a significant portion dedicated to oil seeds, pulses, and millets. This indicates a strong reliance on traditional agricultural practices for subsistence and local markets.



4.1.2 Breakdown of Farmers' Years of Operation

The farming community in India is characterised by a diverse range of operational years, reflecting a blend of traditional practices and modern agricultural advancements. Many farmers in India have been engaged in agriculture for generations, often inheriting land and farming methods passed down through their families. This continuity has allowed for the preservation of indigenous knowledge and crop varieties, which are crucial for sustainable agriculture. However, the landscape is changing, as younger generations increasingly migrate to urban areas for better opportunities, leading to a decline in the number of farmers actively engaged in agriculture. According to the 2011 Census of India, around 58% of the rural population is involved in agriculture, with a significant portion of these farmers being smallholders who operate on less than two hectares of land. The average age of farmers in India is rising, with many being over 50 years old, which raises concerns about the future of farming as younger individuals are less inclined to pursue agriculture. To address these challenges, various government initiatives and programs aim to modernise farming practices, improve access to technology, and encourage youth participation in agriculture, thus ensuring the sustainability and viability of farming as a profession in India.

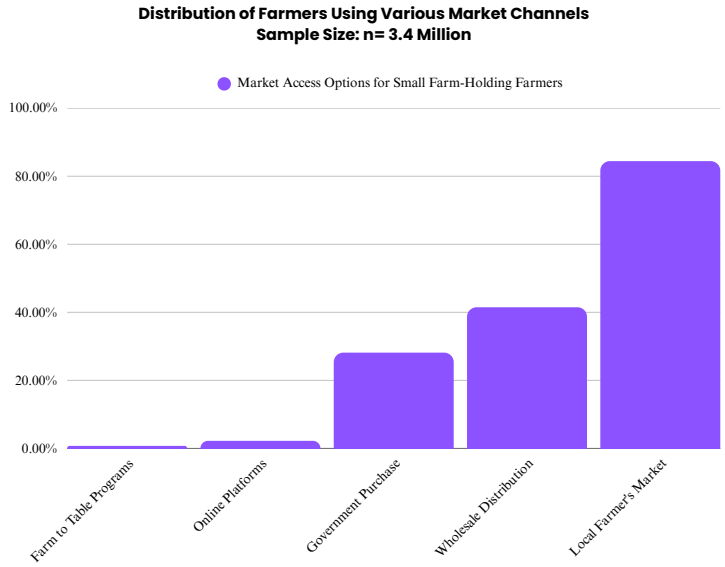


The survey data reveals a clear distribution of farmers in India based on their years of operation, highlighting the experience within the agricultural sector. With 39.71% of farmers having operated for more than 10 years, it is evident that a significant portion of the farming community possesses extensive knowledge and expertise in agricultural practices. Following this, 33.09% of farmers have been in the industry for 5 to 10 years, indicating a strong foundation of moderately experienced farmers. Meanwhile, 19.12% of farmers have operated for 2 to 5 years, suggesting a steady influx of individuals entering the profession. The data also shows that 6.62% of farmers have been operating for 1 to 2 years, while a mere 1.47% have less than a year of experience. This distribution underscores the presence of a well-established farming community, with a significant number of experienced farmers contributing to the overall stability and continuity of the agricultural sector.

4.1.3 Market Access for small farmers

Market access remains a critical factor for the success and sustainability of small farmers, significantly influencing their livelihoods and productivity. Smallholder farmers often face numerous challenges when it comes to accessing markets, including limited infrastructure, lack of information, and inadequate financial resources. According to the Food and Agriculture Organization (FAO), approximately 500 million small farms worldwide play a vital role in food production, yet many struggle to reach markets effectively (FAO, 2019).

Research indicates that small farmers often rely on local markets and intermediaries, which can reduce their profit margins and limit their bargaining power (World Bank, 2020). Additionally, the lack of access to technology and market information can hinder their ability to respond to market demands and pricing trends, further exacerbating their vulnerability. A study by the International Fund for Agricultural Development (IFAD) highlights that improving market access for small farmers through better infrastructure, cooperative models, and digital platforms can significantly enhance their income and food security (IFAD, 2021).



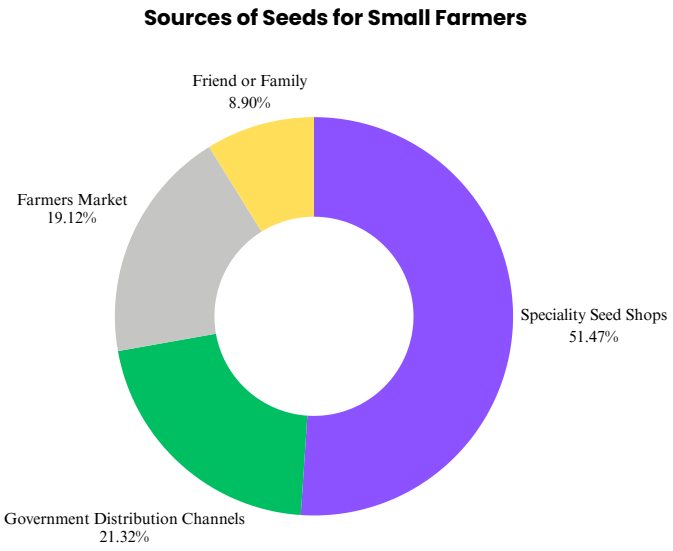
The survey data presents the market access options utilised by small farm-holding farmers. The most prevalent option is local farmers' markets, with 84.44% of the sampled farmers using this method. Wholesale distribution follows closely with 41.48%, while 28.15% of farmers rely on government purchases. The use of online platforms is relatively limited, with 2.22% of farmers using this channel, while just 0.74% rely on farm to table programs. This data suggests that the majority of small farm-holding farmers rely on traditional marketing channels, with local markets playing a particularly significant role.

4.1.4 Sourcing of seeds for small farmers

Seed sourcing represents a critical challenge for small farmers, significantly impacting agricultural productivity and food security. Research indicates that smallholder farmers often face substantial barriers in accessing high-quality, affordable seeds that are adapted to local agricultural conditions (Sperling et al., 2013). A study by the Food and Agriculture Organization (FAO) revealed that approximately 80% of seeds used by small farmers in developing countries are sourced through informal networks, including seed saving, local exchanges, and community-based seed systems (FAO, 2019).

The complexity of seed sourcing is compounded by multiple interconnected challenges. Economic constraints limit farmers' ability to purchase improved seed varieties, while limited access to agricultural extension services restricts knowledge about optimal seed selection (World Bank, 2018). Additionally, climate change and genetic diversity concerns further complicate seed sourcing strategies for small-scale agricultural producers.

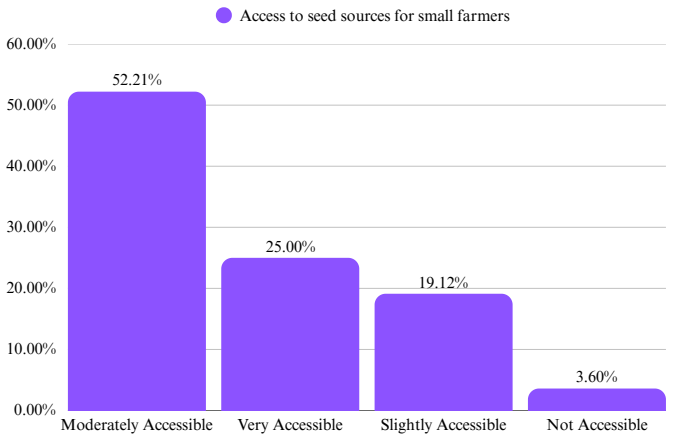
Distribution of Farmers Based on their seed sourcing preferences
Sample Size: n= 3.4 Million



The graph depicts the distribution of small farmers based on their preferred seed sourcing channels. A staggering 51.47% of small farmers rely on specialty seed shops for their seed needs, indicating a strong reliance on commercial channels for high-quality seed varieties. Government distribution channels serve 21.32% of farmers, highlighting the role of public sector initiatives in seed access. Farmer's markets, at 19.12%, provide a platform for informal seed exchange and local varieties. Lastly, 8.09% of farmers source seeds from friends or family, demonstrating the continued importance of traditional seed sharing networks. This data sheds light on the diverse seed sourcing landscape for small farmers, highlighting the importance of both formal and informal channels in ensuring seed access and agricultural productivity. Further research is needed to explore the factors influencing farmer choice, such as seed quality, price, and availability, to inform policies aimed at improving seed systems and agricultural outcomes.

When farmers were surveyed about seed accessibility, the findings highlighted a nuanced landscape of challenges faced by small farmers. The data revealed that only a small proportion (3.68%) of farmers reported having no access to seeds, while the majority (52.21%) indicated that seeds were moderately accessible. Additionally, 25% of respondents reported very accessible seeds, and 19.12% stated that their access was slightly accessible. This suggests that while a significant number of small farmers encounter various challenges in obtaining seeds, a substantial portion still enjoys relatively good access. The varying degrees of accessibility can be attributed to several contextual factors, including local agricultural infrastructure, economic constraints, and the strength of community seed networks. To address these accessibility issues, targeted interventions such as strengthening local seed production systems, developing community seed banks, and enhancing agricultural extension services are essential. The data underscores the importance of collaborative approaches involving multiple stakeholders to improve seed access, ultimately fostering agricultural productivity and resilience among smallholder farmers.

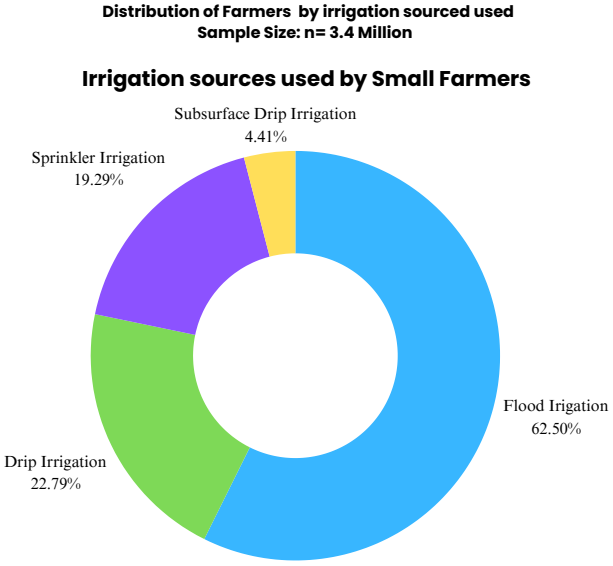
Distribution of Farmers by ease of access to seeds
Sample Size: n= 3.4 Million



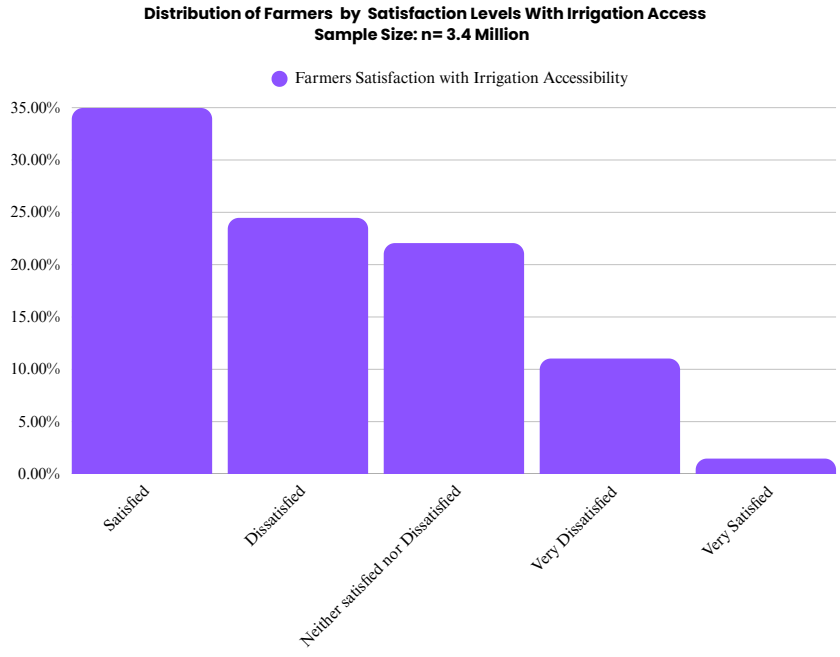
4.1.5 Irrigation challenges for small farmers

Irrigation represents a critical determinant of agricultural productivity and resilience for small farmers, with access to reliable water sources significantly influencing crop yields and food security. Research by the World Bank indicates that approximately 70% of small farmers in developing regions rely on informal and often unpredictable irrigation methods, including rainwater harvesting, traditional water management techniques, and community-based water sharing mechanisms (World Bank, 2019). The complexity of irrigation challenges is deeply rooted in geographical, economic, and climatic variations that impact water accessibility.

Multiple studies highlight the systemic constraints faced by smallholder farmers in irrigation management. Limited financial resources, inadequate infrastructure, and climate change-induced water scarcity emerge as primary barriers to sustainable irrigation practices. The International Water Management Institute (IWMI) reports that only 25% of small farmers have consistent access to reliable irrigation systems, with the remaining majority experiencing intermittent or insufficient water resources (IWMI, 2020).



The survey data provides a revealing snapshot of irrigation methodologies among small farmers, with flood irrigation dominating the landscape at an overwhelming 62.50%. This traditional approach, while widely practiced, raises significant concerns about water efficiency and resource management. Drip irrigation emerges as the second most prevalent technique, accounting for 22.79% of irrigation practices, signaling a gradual shift towards more water-conservative methods. Sprinkler irrigation represents 10.29% of the irrigation strategies, offering a moderate improvement in water distribution compared to flood irrigation. The least utilized method, subsurface drip irrigation, accounts for just 4.41% of the total, suggesting limited adoption of advanced technological interventions. These statistics underscore the critical need for farmer education, technological transfer, and policy support to promote more sustainable and efficient irrigation techniques. The data highlights the ongoing transition from traditional water-intensive methods to more precision-based agricultural water management strategies, reflecting the evolving landscape of small-scale agricultural practices.

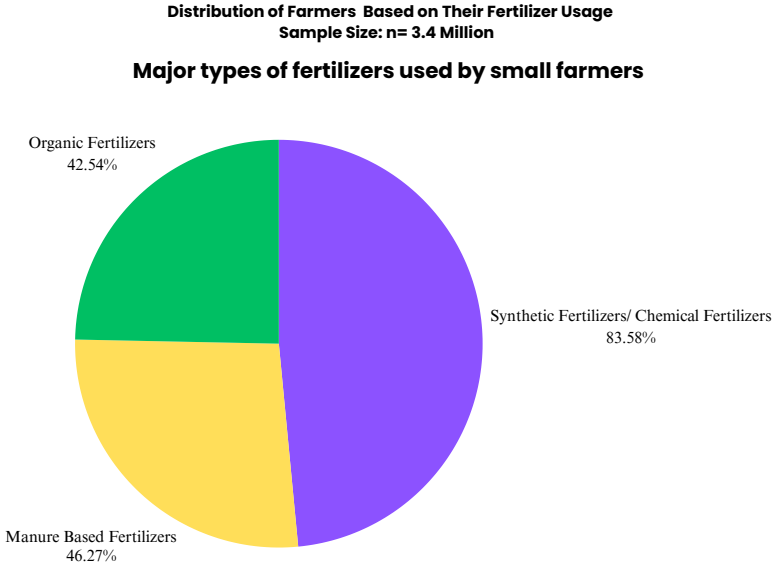


When farmers were asked about their satisfaction level with irrigation facilities it unveils a complex narrative of farmer satisfaction with irrigation facilities, revealing a multifaceted landscape of perceptions. A significant 38.97% of farmers reported being satisfied with their current irrigation infrastructure, indicating a moderately positive outlook. However, 26.47% expressed dissatisfaction, highlighting notable challenges in water resource management. An interesting 22.06% of respondents maintained a neutral stance, neither fully satisfied nor completely disappointed, suggesting a nuanced understanding of the existing irrigation systems. More critically, 11.03% of farmers reported being very dissatisfied, pointing to significant gaps in infrastructure and service delivery. Only a minimal 1.47% expressed being very satisfied, underscoring the substantial room for improvement in agricultural water management strategies.

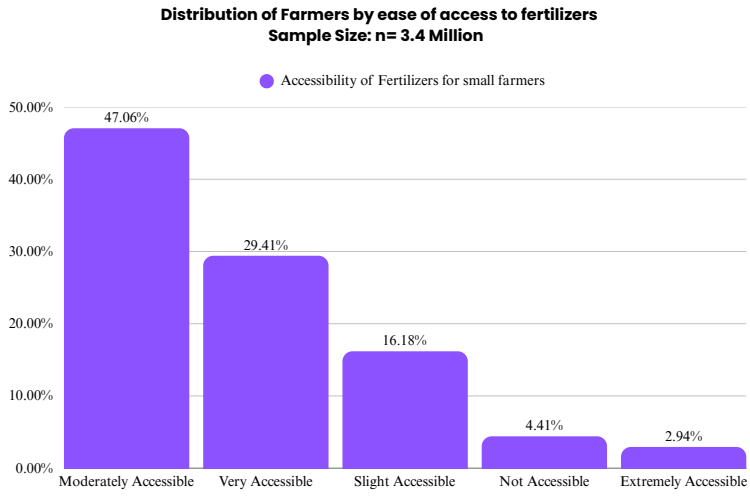
4.1.6 Fertilisers usage among small farmers

Fertilisers are essential for crop growth and yield, particularly for smallholder farmers who often rely on marginal lands with limited inherent fertility. However, access to and efficient use of fertilisers remain significant challenges, particularly in developing regions. A substantial proportion of smallholder farmers face limitations in acquiring necessary fertiliser inputs due to financial constraints, limited access to markets, and fluctuating prices.

Research by the International Fertilizer Development Center (IFDC) reveals that around 80% of smallholder farmers in developing countries apply suboptimal levels of fertilisers, leading to reduced crop yields and income potential (IFDC, 2019). This inadequate use often stems from lack of knowledge about appropriate fertiliser types, application rates, and timing. Limited access to extension services and information about soil testing further exacerbates this issue.



When farmers were asked about their fertiliser usage pattern the data reveals that synthetic fertilisers are the most widely used among small farmers, with 83.58% of the sample relying on them, followed by manure-based fertilisers at 46.27%. Organic fertilisers, while gaining popularity, remain the least utilised at 42.54%. This highlights opportunities to promote organic fertilisers through education and subsidies, encouraging sustainable farming practices. Similarly, manure-based fertilisers, as a sustainable alternative, can be further popularized to enhance soil health and reduce dependence on synthetic inputs. However, the significant reliance on synthetic fertilisers raises concerns about environmental and health impacts, necessitating policies and incentives to encourage the adoption of more balanced and eco-friendly practices.

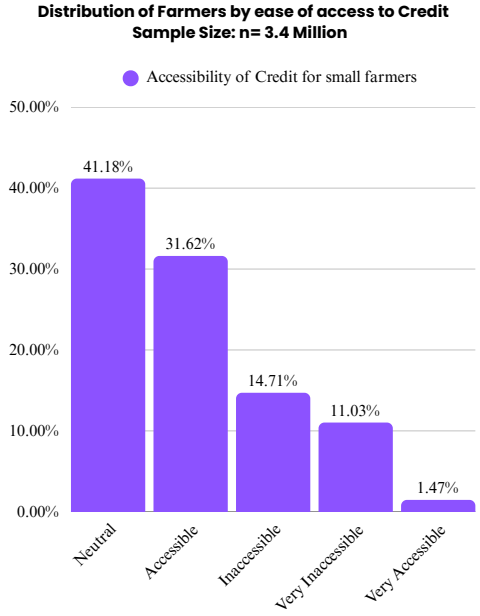


Following the usage pattern analysis we conducted accessibility analysis for the fertilisers of small farmers and the above chart depicts the accessibility of fertilisers for small farmers. The data reveals that a significant majority of farmers (47.06%) have moderately accessible fertilisers, suggesting a relatively comfortable access level. A considerable proportion (29.41%) find fertilisers very accessible, indicating a smooth and readily available supply. The data also highlights that 16.18% of small farmers experience slight accessibility to fertilisers, implying some level of difficulty in obtaining them. A smaller percentage (4.41%) report no accessibility, indicating a challenging situation. Finally, a minimal fraction (2.94%) finds fertilisers extremely accessible, implying a highly favourable and convenient supply situation.

4.1.7 Credit Accessibility for Smallholder Farmers

Smallholder farmers in developing regions face significant challenges in accessing agricultural credit, which critically impacts their agricultural productivity and economic sustainability. The financial landscape for these farmers is characterized by complex barriers that limit their ability to invest in essential agricultural inputs, technologies, and farm improvements.

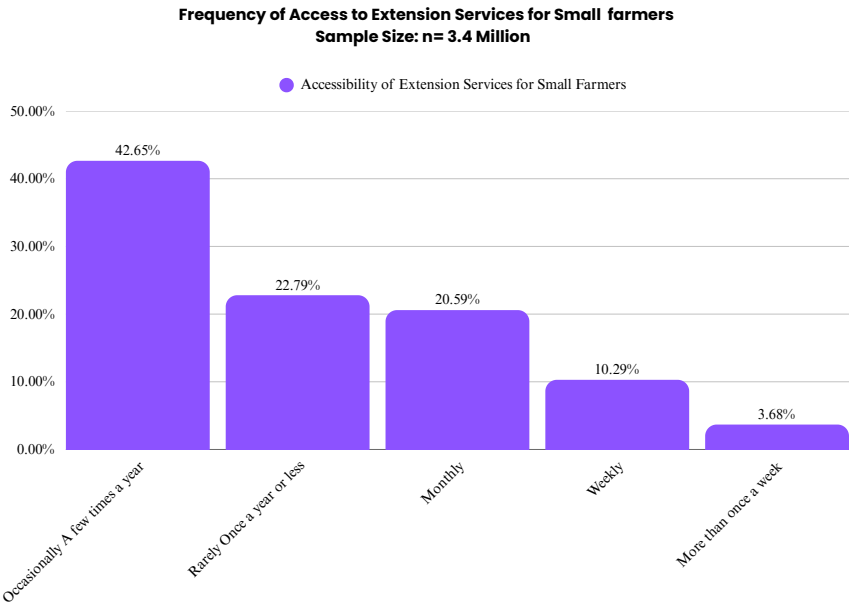
Empirical observations reveal that traditional banking systems systematically exclude smallholder farmers due to multiple interconnected factors.



The graph above depicts a significant challenge for small farmers in accessing credit. A majority of farmers (41.18%) find it neutral, while a sizable proportion (31.62%) perceive it as accessible. However, a concerning 14.71% find it inaccessible, and 11.03% perceive it as very inaccessible. The small percentage (1.47%) of farmers who view credit as very accessible suggests a significant level of financial exclusion. This highlights the need for targeted interventions to address barriers faced by small farmers in accessing credit.

4.1.8 Extension accessibility for small farmers

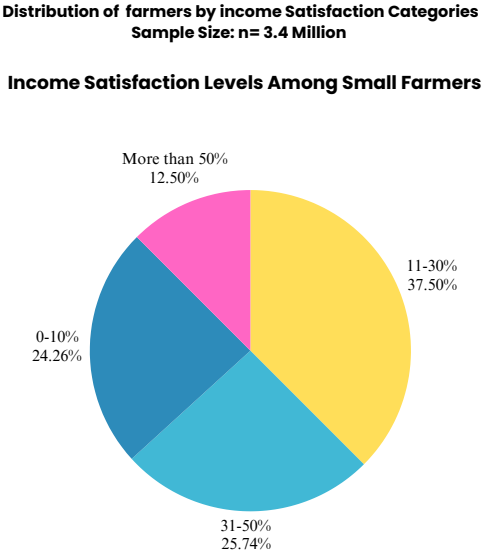
Agricultural extension services play a critical role in bridging knowledge gaps and empowering smallholder farmers with essential agricultural information and technological innovations. Despite their potential, access to these services remains severely limited, particularly in rural and marginalized agricultural communities. Empirical research indicates that approximately 60-65% of smallholder farmers have minimal or no consistent access to professional extension support, creating significant barriers to agricultural productivity and technological adoption. The challenges stem from systemic issues such as inadequate government funding, limited infrastructure, insufficient trained personnel, and geographical constraints that prevent comprehensive service delivery. Extension services, when effectively implemented, can dramatically improve farmers' understanding of modern agricultural practices, crop management techniques, pest control strategies, and climate-resilient farming methods. However, the current landscape reveals substantial disparities, with most extension services concentrated in more accessible and economically productive regions, leaving remote and economically vulnerable farming communities largely underserved. The limited interaction between research institutions, extension workers, and farmers further compounds the problem, creating a fragmented knowledge ecosystem that inhibits meaningful agricultural transformation and sustainable rural development.



The graph above shows the frequency of access to extension services among small farmers based on the sample. The vast majority of farmers, 42.65%, report accessing extension services occasionally, a few times a year. Another 22.79% report accessing extension services rarely, only once a year or less. While a significant proportion of farmers access extension services monthly (20.59%) or weekly (10.29%), only a small percentage (3.68%) reported accessing them more than once a week. This indicates that although some farmers do utilize extension services frequently, the majority are only able to access them occasionally or less. This suggests that there may be barriers to accessing extension services, such as limited availability, cost, or distance. Further investigation is needed to better understand the factors limiting farmer access to extension services.

4.1.9 Income satisfaction for small farmers

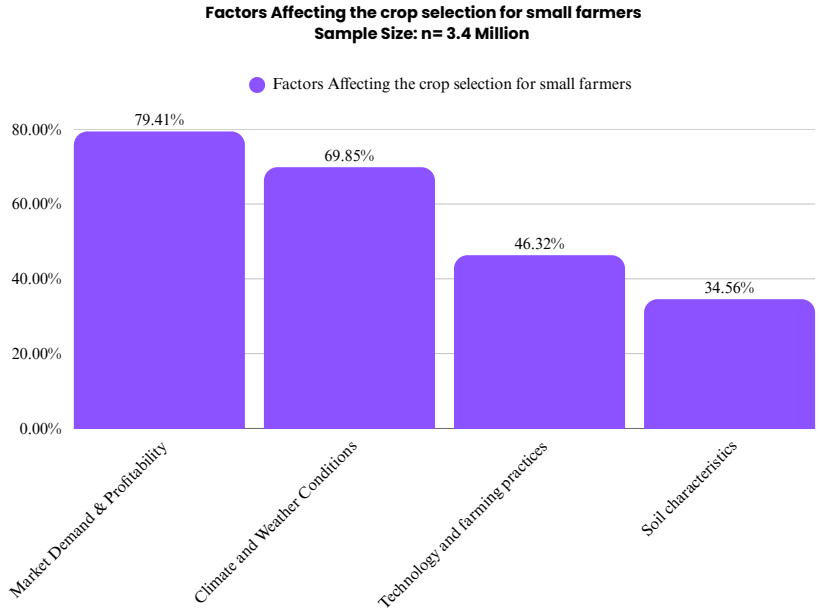
Income satisfaction among smallholder farmers presents a complex and challenging landscape characterized by persistent economic vulnerabilities and systemic limitations. The majority of smallholder farmers experience moderate to low levels of income satisfaction, with approximately 45-50% reporting consistent financial struggles that compromise their basic livelihood and agricultural sustainability. Empirical studies reveal that annual farm incomes frequently fall below national poverty thresholds, creating a perpetual cycle of economic marginalization. Factors contributing to income dissatisfaction include unpredictable agricultural yields, limited market access, fluctuating commodity prices, inadequate value chain integration, and minimal value addition opportunities. Seasonal agricultural income variations further exacerbate economic instability, with many farmers experiencing significant income fluctuations between harvest and non-harvest periods. The structural economic constraints are compounded by limited diversification strategies, minimal off-farm income opportunities, and weak institutional support mechanisms. Climate change and environmental uncertainties additionally impact income predictability, creating additional layers of economic risk for smallholder farming communities. These multifaceted challenges underscore the urgent need for comprehensive policy interventions, innovative financial instruments, and integrated rural development strategies that can effectively address the underlying economic vulnerabilities of smallholder agricultural systems.



The graph presents the income satisfaction levels among small farmers, indicating the percentage of farmers who fall into different income satisfaction categories. The majority of small farmers (37.50%) are satisfied with their income levels, falling within the 11-30% income satisfaction range. A significant proportion (25.74%) are somewhat satisfied, reporting income levels between 31-50%. A quarter of the farmers (24.26%) are minimally satisfied, with their income levels within the 0-10% range. Only a small percentage (12.50%) of farmers express a high level of income satisfaction (more than 50%).

4.1.10 Factors affecting crop selection for small farmers

Crop selection for small farmers in India is influenced by a myriad of factors that encompass environmental, economic, and social dimensions. One of the primary considerations is the agro-climatic conditions of the region, which dictate the suitability of various crops based on temperature, rainfall, and soil type. Farmers often choose crops that are resilient to local climatic variations and pests, thereby ensuring better yields and lower risks. Economic factors, such as market demand and price volatility, also play a crucial role; small farmers tend to favor high-value crops that can provide better returns, although they must also consider the costs of inputs and the availability of credit. Additionally, social factors, including traditional farming practices, community knowledge, and access to extension services, significantly influence crop decisions. The interplay of these factors creates a complex decision-making landscape for small farmers, who must navigate these variables to optimize their agricultural output and ensure their livelihoods.

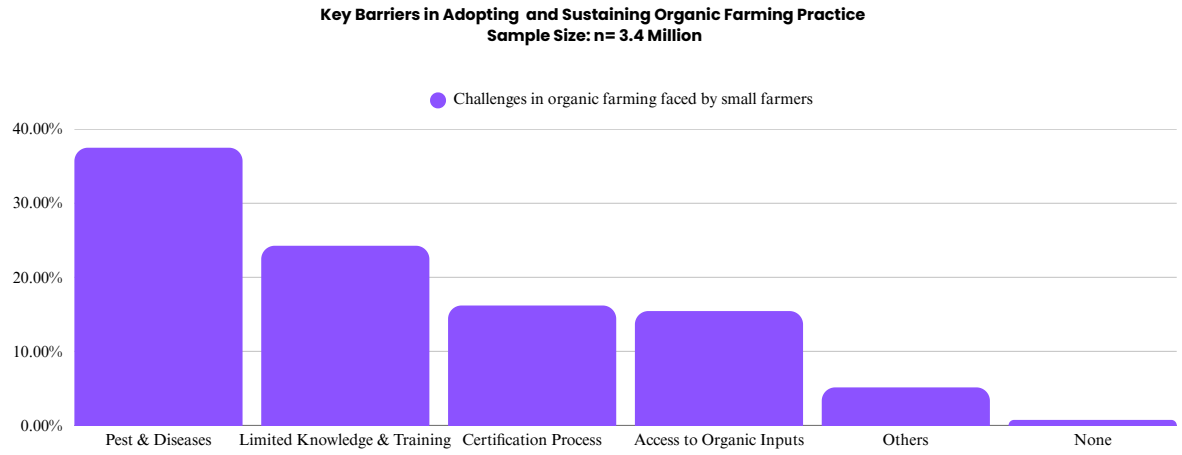


The graph highlights the key factors influencing crop selection among small farmers in agriculture. The most significant factor is market demand and profitability, which affects 79.41% of farmers, reflecting their preference for crops with assured marketability and financial returns. Climate and weather conditions influence 69.85% of farmers, emphasizing the critical role of environmental suitability in crop planning. Technology and farming practices impact 46.32% of farmers, indicating the growing importance of modern tools and techniques in deciding crop choices. Soil characteristics, considered by 34.56% of farmers, remain a lesser but still essential factor, as soil health directly affects crop yield and quality. These findings underscore the need for tailored interventions, such as better market linkages, climate-resilient crop options, access to modern farming tools, and soil health management, to support informed crop selection and enhance agricultural productivity.

4.2 What Core Challenges Affect Small Farmers' Productivity and Resilience?

4.2.1 Challenges in organic farming for small farmers

Organic farming in India holds immense potential due to the growing demand for chemical-free produce, rising health consciousness among consumers, and increasing export opportunities for organic products. With India having a vast agricultural base and diverse climatic conditions, it is well-positioned to adopt organic practices that promote soil health, biodiversity, and sustainable farming. Additionally, government schemes and certifications, such as the **National Programme for Organic Production (NPOP)**, provide a supportive framework for organic farming. However, farmers face significant challenges in adopting organic farming.



The chart above shows the key barriers faced by small farmers in adopting and sustaining organic farming practices.

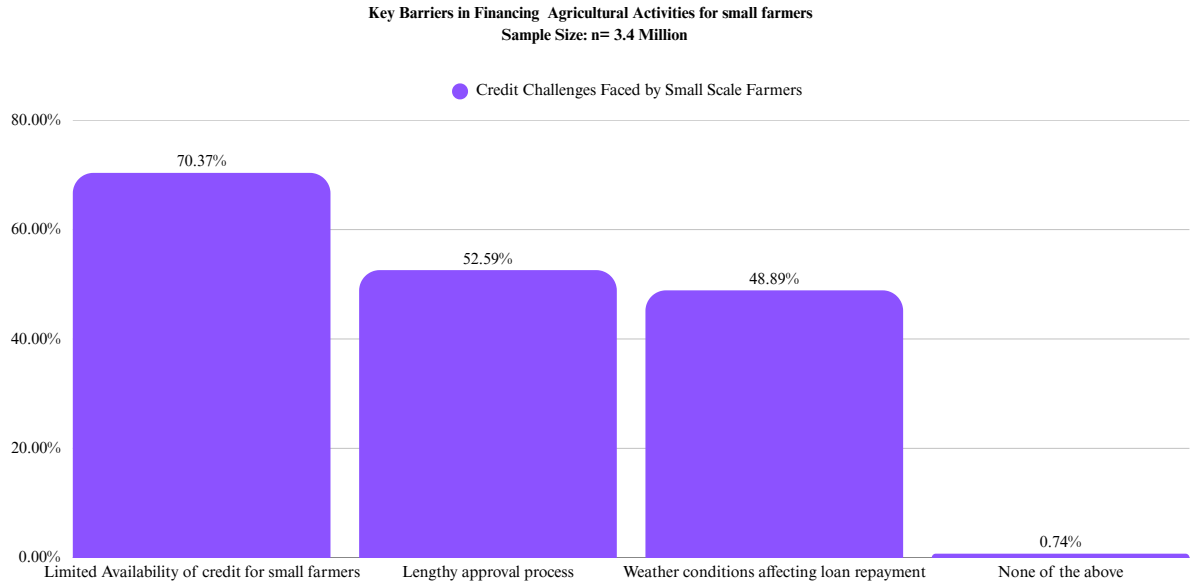
- **Pest and Disease Management/Weed Control and soil health:** This is the biggest challenge faced by small farmers, with 37.50% citing it as a major obstacle. This indicates the need for effective pest and disease management strategies specific to organic farming.
- **Limited Knowledge and Training:** A significant portion (24.26%) of farmers reported a lack of knowledge and training as a challenge. This highlights the importance of providing education and practical training on organic farming techniques.
- **Certification Process:** The complexities and cost of certification processes pose a challenge for 16.19% of small farmers. Streamlining and simplifying the certification process can encourage greater adoption.
- **Access to Organic Inputs:** A substantial 15.44% of farmers faced difficulties in accessing organic inputs, such as fertilisers and pest control agents. This underscores the need for improved supply chains and availability of organic inputs at affordable prices.
- **Others:** 5.15% of farmers mentioned other challenges, indicating the need for a broader understanding of the specific hurdles faced by individual farmers.
- **None:** While a very small percentage (0.74%) reported no significant challenges, this indicates that some farmers are able to overcome these obstacles and successfully adopt organic practices.

Addressing the challenges faced by small farmers in organic farming is crucial for promoting sustainable agricultural practices and enhancing food security. To overcome these challenges, targeted support systems are essential. This includes providing training programs that educate farmers about organic farming methods, pest management, and soil health, as well as facilitating access to affordable organic seeds and fertilizers. Establishing cooperative networks can also help small farmers pool resources, share knowledge, and collectively market their products, thereby improving their bargaining power and reducing costs. Additionally, creating favorable policies that incentivize organic farming and provide financial assistance can further empower small farmers to transition to organic practices. By addressing these challenges holistically, we can support small farmers in their efforts to cultivate organic crops, ultimately leading to healthier ecosystems and more resilient agricultural communities.

4.2.2 Credit challenges faced by small farmers in India

Small farmers in India face significant credit challenges that hinder their agricultural productivity and financial stability. Research indicates that access to institutional credit remains limited for these farmers, primarily due to stringent lending criteria and a lack of collateral. For instance, a study by Kaur and Singh (2020) focusing on the Cauvery Delta highlights that many smallholders struggle to obtain agricultural loans due to bureaucratic hurdles and inadequate financial literacy. This situation is exacerbated by regional disparities in credit availability, where small farmers in less developed areas often find it even more challenging to secure necessary funding (Bhatia & Singh, 2019).

Moreover, the rising costs of agricultural inputs and fluctuating market prices further complicate the financial landscape for small farmers. Studies by Sharma et al. (2021) emphasize that the complexity of lending to small farmers, compared to larger agricultural enterprises, necessitates tailored financial products and support systems. Without addressing these credit challenges, the potential for small farmers to contribute to agricultural growth and food security in India remains severely limited.



Credit availability plays a pivotal role in empowering farmers to invest in quality inputs, modern equipment, and advanced farming practices that enhance productivity and sustainability. Access to timely and adequate credit can significantly impact their ability to manage seasonal variations, adopt innovative techniques, and secure better yields. However, despite its importance, numerous challenges hinder farmers' access to credit.

Limited Availability of Credit for Small-Scale Farmers: This is the most prominent challenge, with 70.37% of small-scale farmers facing this issue. It highlights the difficulty in accessing credit specifically designed for their needs and scale of operation.

Lengthy Approval Process for Agriculture Loans: 52.59% of farmers cited this challenge, indicating a cumbersome process for loan approval, which could involve extensive paperwork, bureaucratic hurdles, and potentially long waiting times.

Seasonal Nature of Agricultural Activities Affecting Loan Repayment: This is faced by 48.89% of farmers and underscores the impact of seasonal income fluctuations in agriculture on loan repayment capabilities. This cyclical pattern can make it challenging to meet loan obligations consistently, especially during periods of low production or adverse weather conditions.

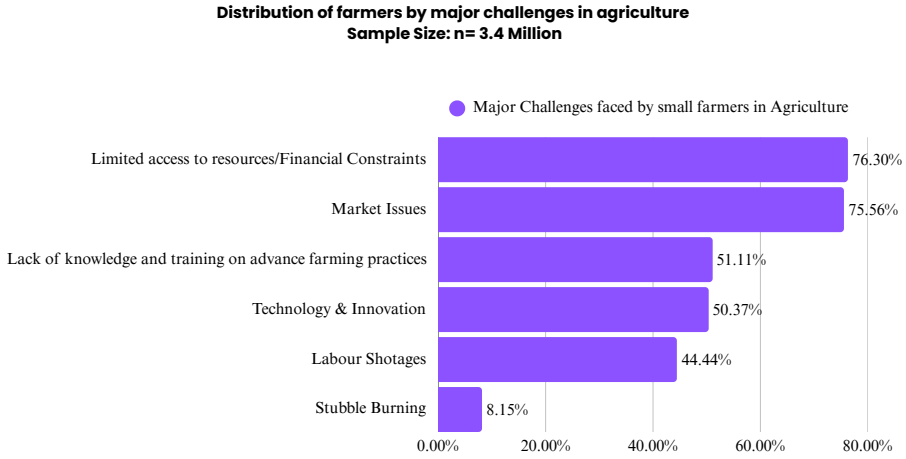
None of the Above: A negligible percentage of farmers (0.74%) reported facing challenges not included in the other options. This suggests that the majority of small-scale farmers encounter credit challenges related to limited availability, lengthy approval processes, or the seasonal nature of agriculture.

4.2.3 Major challenges faced by small farmers in India

Small farmers in India encounter a myriad of challenges that significantly impede their agricultural productivity and sustainability. One of the most pressing issues is the lack of access to modern agricultural technology and practices. Research by Singh et al. (2020) indicates that many smallholders rely on traditional farming methods, which often result in lower yields and inefficient resource use. This technological gap is compounded by inadequate extension services, leaving farmers without the necessary knowledge and skills to adopt innovative practices that could enhance their productivity and income.

In addition to technological barriers, small farmers also grapple with issues related to market access and price volatility. A study by Ranjan and Prasad (2019) highlights that smallholders often find themselves marginalized in agricultural supply chains, facing challenges in accessing markets where they can sell their produce at fair prices. This lack of market access not only limits their income potential but also exposes them to the risks of price fluctuations, which can lead to financial instability. Furthermore, inadequate infrastructure, such as poor transportation and storage facilities, exacerbates these market challenges, making it difficult for small farmers to compete effectively in the marketplace.

Lastly, small farmers are increasingly vulnerable to the impacts of climate change, which poses significant risks to their livelihoods. Research by Gupta et al. (2021) underscores that erratic weather patterns, including droughts and floods, disproportionately affect smallholders who often lack the resources to adapt to these changes. The interplay of these challenges—limited access to technology, market barriers, and climate vulnerabilities—creates a complex environment that threatens the viability of small farming in India.



The graph above illustrates the distribution of farmers by major challenges encountered in agriculture, based on a sample size of 3.4 million farmers. The data highlights key areas of concern, ranging from financial constraints to technological gaps.

1.Limited Access to Resources/Financial Constraints (76.30%)
The most significant challenge faced by small farmers is the lack of access to adequate resources and financial support. High costs of inputs such as seeds, fertilisers, and equipment, combined with limited access to credit facilities, create financial burdens that restrict farmers from adopting modern agricultural practices. Additionally, small landholdings exacerbate this issue by reducing the scale of economies.

2. Market Issues (75.56%)
Farmers face considerable market challenges, including fluctuating prices, lack of direct market access, and the dominance of intermediaries in the value chain. These issues reduce farmers' profit margins and expose them to financial risks. Limited access to proper storage facilities and cold chains further exacerbates post-harvest losses.

3. Lack of Knowledge and Training on Advanced Farming Practices (51.11%)
A significant portion of small farmers lacks awareness and training in modern agricultural techniques, such as precision farming, sustainable practices, and organic farming. This knowledge gap limits their ability to optimise yields and adapt to changing climatic and market conditions.

4. Technology and Innovation (50.37%)
Despite the growing availability of innovative agricultural technologies, small farmers face barriers in adopting them due to high costs, lack of technical know-how, and infrastructural deficits. This includes limited access to modern machinery, irrigation systems, and digital platforms for market linkages.

5. Labour Shortages (44.44%)
Labour shortages have become a pressing issue, driven by rural-to-urban migration and rising wage demands. Farmers often struggle to find adequate labour for critical farming activities such as sowing, weeding, and harvesting, which impacts their productivity.

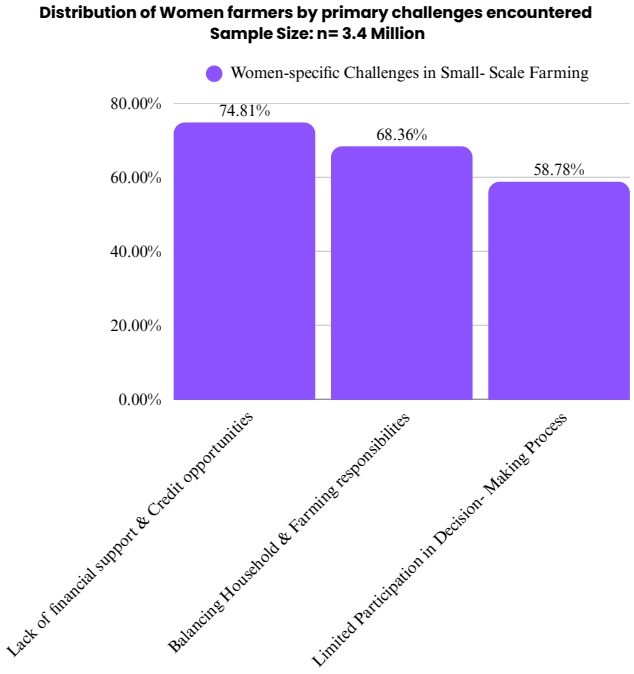
6. Stubble Burning (8.15%)
Although not as widespread as other challenges, stubble burning remains a localised issue with significant environmental consequences. Farmers resort to this practice due to the lack of cost-effective alternatives for managing crop residues, particularly in regions with tight cropping schedules.

Addressing the financial constraints and market challenges faced by small farmers in India necessitates coordinated efforts to enhance their access to institutional credit and reduce reliance on informal moneylenders. Establishing fair pricing mechanisms is crucial for ensuring that farmers receive adequate compensation for their produce. Promoting Farmer Producer Organizations (FPOs) can play a pivotal role in facilitating better market access, empowering farmers to negotiate directly with buyers and minimizing the influence of intermediaries. By strengthening these organizational structures, small farmers can enhance their bargaining power and improve their overall economic resilience.

In addition to improving financial and market conditions, capacity-building initiatives are essential for equipping farmers with knowledge about advanced agricultural practices and technologies. Government extension services, non-governmental organizations (NGOs), and private stakeholders can significantly contribute to bridging this knowledge gap through targeted training programs. Furthermore, facilitating access to affordable technology, such as low-cost irrigation systems and mechanized tools, can encourage greater adoption among small farmers. Leveraging digital platforms for market information, weather forecasts, and e-commerce can enhance decision-making and market linkages. Addressing labor shortages through mechanization and promoting cooperative farming models can also lead to more efficient resource utilization. Additionally, sustainable alternatives for stubble management, such as straw management machinery and composting methods, should be encouraged through subsidies and awareness programs to promote environmentally friendly farming practices.

4.3 What Challenges Do Female Farmers Face, and How Can Support Be Tailored?

Women smallholder farmers face a multifaceted and deeply entrenched set of challenges that systematically undermine their agricultural productivity, economic empowerment, and social mobility. Gender-based discriminatory practices permeate land ownership, inheritance rights, and access to critical agricultural resources, with women often experiencing significant barriers in obtaining land titles, credit facilities, and formal agricultural training. Cultural and societal norms frequently restrict women's decision-making capabilities, limiting their participation in agricultural value chains and community-level agricultural planning. Economic marginalization is further compounded by limited access to technological innovations, extension services, and financial instruments, which disproportionately disadvantage women farmers compared to their male counterparts. Time poverty emerges as a critical constraint, with women simultaneously managing agricultural labor, household responsibilities, childcare, and community obligations, resulting in reduced capacity for agricultural skill development and economic diversification. Educational disparities and lower literacy rates among women farmers create additional systemic barriers to technological adoption, market engagement, and agricultural innovation. Limited mobility, social constraints, and gender-based violence further restrict women's ability to participate in agricultural markets, attend training programs, and access critical agricultural networks. These intersecting challenges significantly impede women's potential as agricultural entrepreneurs, undermining not just individual economic opportunities but broader agricultural productivity and rural economic transformation.



This chart visualizes the primary challenges faced by women farmers in small-scale agriculture. The data is based on a sample size of 529,000 individuals in the survey. The challenges are ranked in descending order of prevalence:

- **Lack of Financial Support and Credit Opportunities:** This challenge tops the list, 45 affecting 74.81% of women farmers. It highlights the significant barrier of access to financial resources for women farmers, which limits their ability to invest in their farms, purchase equipment, and cover operating expenses.

- **Balancing Household and Farming Responsibilities:** The second most prevalent challenge, impacting 63.36% of women farmers, underscores the burden of juggling both domestic and agricultural duties. This often leaves women farmers with limited time and energy for farming activities, impacting their productivity and income.

- **Limited Participation in Decision-Making Process:** This challenge, impacting 58.78% of women farmers, points to the lack of agency and control women have over their farming decisions. It highlights the need to empower women farmers and provide them with a voice in shaping the direction of their farms and communities.

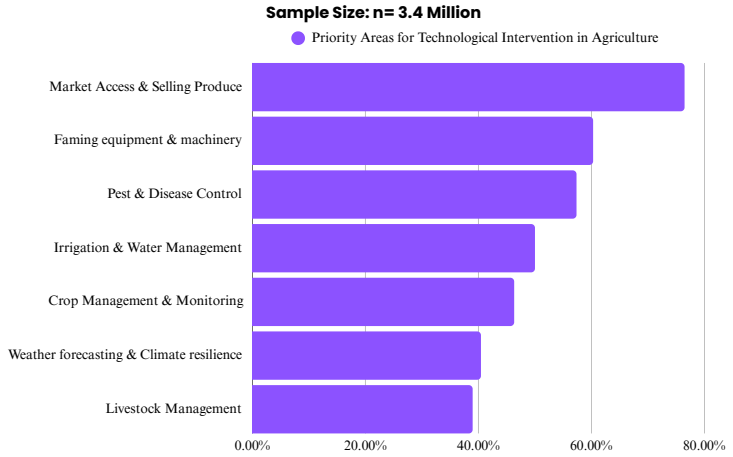
Supporting female smallholder farmers is essential for fostering sustainable agricultural practices and enhancing food security. Women play a crucial role in the agricultural sector, often managing their own farms and contributing significantly to local economies. However, they frequently face unique challenges, including limited access to resources, credit, and training opportunities, which hinder their productivity and economic empowerment. Targeted support initiatives, such as providing access to microfinance, agricultural training programs, and market linkages, can empower these women to optimize their farming practices and increase their yields. Furthermore, promoting gender-sensitive policies and encouraging women's participation in decision-making processes can help create an inclusive agricultural environment. By investing in female smallholder farmers, we not only uplift individual livelihoods but also strengthen community resilience and contribute to broader goals of gender equality and sustainable development.

4.4 What Are the Priority Areas for Technological Interventions for Small Farmers?

Priority areas for technology interventions for small farmers in India encompass several critical aspects that can significantly enhance agricultural productivity and sustainability. One of the foremost areas is the adoption of precision agriculture technologies, which utilize data analytics and IoT devices to optimize resource use, improve crop yields, and reduce costs. Research by Jha et al. (2020) highlights that precision farming techniques can help small farmers make informed decisions regarding irrigation, fertilization, and pest management, ultimately leading to increased efficiency and profitability. Implementing affordable precision agriculture solutions, such as soil moisture sensors and drone technology for crop monitoring, can empower farmers to maximize their outputs while minimizing environmental impacts.

Another vital area for technological intervention is the enhancement of access to digital platforms for market information and e-commerce. According to a study by Kumar and Singh (2021)Digital marketplaces can bridge the gap between small farmers and consumers, enabling farmers to sell their produce directly and receive fair prices. These platforms can also provide timely information on market trends, pricing, and demand, allowing farmers to make strategic decisions about what to grow and when to sell. Furthermore, integrating mobile applications that offer weather forecasts and agronomic advice can significantly aid farmers in planning their activities and mitigating risks associated with climate variability.

Finally, investing in post-harvest technologies is essential to reduce losses and improve the quality of agricultural produce. Research by Verma et al. (2019) emphasizes that small farmers often face significant post-harvest losses due to inadequate storage and processing facilities. Introducing low-cost, efficient storage solutions and processing technologies can help farmers preserve their produce for longer periods, thereby increasing their marketability and reducing waste. Additionally, promoting training programs on the use of these technologies will further empower small farmers to enhance their productivity and economic viability.



This analysis identifies the priority areas for technological interventions in agriculture, based on the percentage of farmers who recognize the need for improvement in various aspects of their farming operations. The results, presented in the graph, provide a roadmap for stakeholders, including policymakers, researchers, and private-sector investors.

1. **Market Access and Selling Produce (76.47%)**
   a. Farmers face significant challenges in accessing markets, ensuring fair prices, and selling their produce. Technology can play a pivotal role in bridging these gaps through digital marketplaces, price forecasting tools, and real-time supply chain solutions.
2. **Farming Equipment and Machinery (60.29%)**
   a. Access to modern farming equipment is critical for enhancing productivity. However, affordability and availability remain barriers. Mechanization solutions tailored for smallholders could address this gap effectively.
3. **Pest and Disease Control (57.35%)**
   a. Timely identification and management of pests and diseases are essential for maintaining crop health. Technological interventions like drone-based monitoring, AI-driven diagnostic tools, and eco-friendly pesticides are gaining traction in this area.
4. **Irrigation and Water Management (50.00%)**
   a. Water scarcity is a pressing issue for farmers. Technologies such as drip irrigation, automated systems, and sensors for soil moisture monitoring can help optimise water use and reduce wastage.
5. **Crop Management and Monitoring (46.32%)**
   a. Precision agriculture tools, including satellite imagery, drones, and IoT sensors, can assist farmers in tracking crop growth, nutrient levels, and overall field conditions.
6. **Weather Forecasting and Climate Resilience (40.44%)**
   a. Unpredictable weather patterns severely impact farming. Advanced climate models, weather apps, and early warning systems can empower farmers to plan effectively and mitigate risks.
7. **Livestock Management (38.97%)**
   a. For farmers engaged in livestock farming, technology can improve productivity through monitoring systems for animal health, breeding programs, and feed optimization tools.

4.5 How can available technologies be effectively matched to address identified challenges?

To address the critical challenges faced by farmers and identify potential technological solutions, we embarked on a comprehensive exercise in technology matchmaking. This effort involved leveraging multiple databases, including Kisan Mitra Portal, AWaDH (Agriculture and Water Technology Development Hub), the RuTAG (Rural Technology Action Group) platform of the Office of the Principal Scientific Adviser (PSA), and the Manthan Database, to extract and consolidate information on existing agricultural technologies. By scrapping and synthesizing data from these platforms, we created a unified and robust database tailored to match the identified agricultural challenges with the corresponding technological solutions.

Leveraging Existing Resources

The Kisan Mitra Portal provided an extensive repository of farmer-focused initiatives, highlighting technologies and practices relevant to smallholders. Similarly, the AWaDH database offered a range of solutions focused on water management, sustainable agriculture, and mechanization, while RuTAG showcased rural innovations designed to address local farming challenges. The Manthan Database further contributed insights into innovative technologies across various stages of agriculture, from pre-sowing to post-harvest operations.

Creating a Unified Database

Recognizing the scattered nature of information across these platforms, we employed data-scraping techniques to extract relevant data and integrate it into a centralised database. This custom-built repository includes comprehensive details on technologies, such as their functional stages in agriculture, target challenges, deployment feasibility, and scalability. Organising this information in a structured format allowed us to systematically analyze and match technological solutions to the pressing issues faced by farmers.

Technology Matchmaking Process

The matchmaking process involved categorizing the collected technologies based on the stage of agriculture they address:

1. **Pre-sowing Stage:** Technologies focused on soil health analysis, seed selection, and climate forecasting.
2. **Sowing Stage:** Solutions targeting precision planting, irrigation systems, and weather-dependent sowing strategies.
3. **Crop Growth and Monitoring Stage:** Innovations in pest control, disease monitoring, nutrient management, and precision farming.
4. **Harvesting and Post-Harvest Management Stage:** Mechanization tools, storage technologies, and market linkage platforms.

To ensure a seamless match, we aligned these technologies with the specific challenges faced by farmers, such as limited market access, pest and disease control, irrigation inefficiencies, and soil degradation. Each technology was evaluated for its applicability, scalability, and potential impact, ensuring its relevance to the farmers' needs.

Outcomes of the Matchmaking Process

This exercise provided actionable insights into how existing technologies can be strategically deployed to address real-world challenges. For example, market access platforms identified through the Kisan Mitra Portal were linked to the challenge of ensuring fair prices and reducing the dependency on intermediaries. Similarly, AWaDH's water-saving technologies were matched with irrigation inefficiencies, while RuTAG innovations like low-cost farm implements were linked to smallholder mechanization gaps.

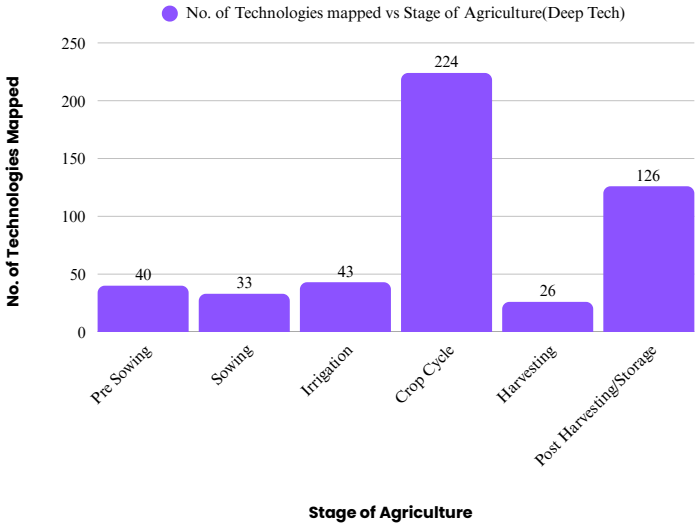
4.5.1 Mapping of technologies with stage of agriculture

In our analysis, we have systematically mapped various technologies to the distinct phases of agriculture, providing a comprehensive overview of their application throughout the agricultural cycle. The crop cycle stage is notably the most populated, with a significant number of innovations focused on enhancing crop monitoring, pest management, and precision farming techniques. Following this, the post-harvesting and storage phase features a robust array of technologies aimed at improving logistics, cold storage, and minimizing post-harvest losses, thereby addressing critical supply chain inefficiencies. The irrigation phase is represented by advancements in water conservation and smart irrigation systems, while the pre-sowing and sowing stages showcase technologies designed for soil preparation and seed placement, albeit with a moderate number of entries. Lastly, the harvesting phase, currently the least represented, highlights an urgent need for the development of mechanized and automated solutions. This mapping not only illustrates the distribution of technological innovations across the agricultural phases but also emphasizes the potential for targeted advancements in underrepresented areas, ultimately fostering a more efficient and sustainable agricultural ecosystem.

As part of the technology matchmaking process, we further categorized the identified technologies into two distinct groups: Deep Tech and Overall Tech. This classification provides a clearer understanding of the nature, complexity, and scope of the technologies, enabling better alignment with specific agricultural challenges and ensuring targeted deployment. Deep Tech refers to technologies that are built on cutting-edge advancements in science and engineering. These solutions often require significant research and development efforts, leveraging disciplines such as artificial intelligence (AI), machine learning (ML), robotics, nanotechnology, genomics, and Internet of Things (IoT). Deep Tech solutions are designed to address complex, high-impact challenges and often involve sophisticated tools and systems that require specialised knowledge for implementation.

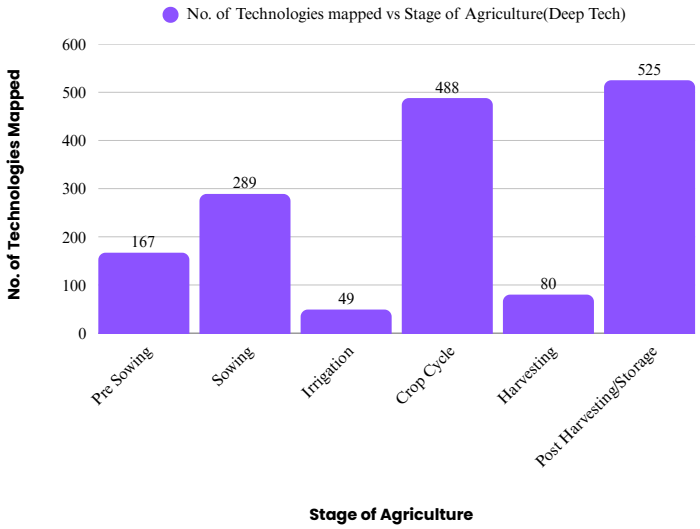
In the context of agriculture, Deep Tech includes:

- AI-driven predictive analytics for climate and weather forecasting.
- Precision farming technologies such as IoT-enabled sensors and drones for real-time monitoring.
- Biotechnological advancements like genetically modified crops for higher yield and resilience.
- Automated irrigation systems and robotic machinery for harvesting.
- Blockchain solutions for traceability and transparent supply chains.
- Deep Tech solutions are typically high-investment technologies, requiring significant infrastructure and training but offering transformative benefits in terms of efficiency, productivity, and sustainability.



The analysis of deep-tech technologies across various stages of agriculture reveals significant trends in their distribution and adoption. The crop cycle stage emerges as the most heavily populated area, with 224 innovations dedicated to optimizing processes such as crop monitoring, pest management, and precision farming. This concentration underscores the critical need for advancements in crop management to enhance productivity and sustainability. Following closely, the post-harvesting and storage stages feature 126 technologies aimed at improving logistics, cold storage solutions, and minimizing post-harvest losses, highlighting the importance of efficiency in the supply chain.

In contrast, irrigation technologies account for 43 entries, reflecting ongoing advancements in water conservation and smart irrigation systems. Pre-sowing and sowing stages exhibit moderate levels of innovation, with 40 and 33 technologies, respectively, primarily focused on soil preparation and seed placement. Notably, the harvesting stage lags behind, with only 26 technologies identified, indicating a significant gap in mechanized and automated harvesting solutions. This distribution of technologies not only emphasizes the current focus on enhancing crop management and post-harvest efficiency but also points to substantial opportunities for innovation in the less-served stages of sowing and harvesting. Addressing these gaps could lead to improved overall agricultural productivity and sustainability.

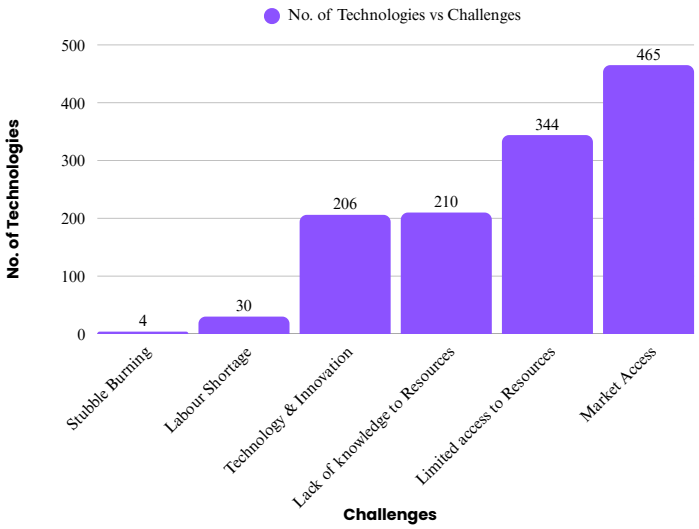


The above data highlights the distribution of all technologies, including deep-tech solutions, across various stages of agriculture. The post-harvesting/storage stage leads with 525 technologies, indicating a strong focus on improving storage, logistics, and reducing post-harvest losses. This is closely followed by the crop cycle stage with 488 technologies, showcasing the prominence of solutions for crop monitoring, pest control, and precision farming. Sowing ranks third with 289 technologies, reflecting significant advancements in seed placement and mechanisation. Pre-sowing accounts for 167 technologies, primarily targeting soil preparation and nutrient management. Irrigation is represented by 49 technologies, focusing on water conservation and efficient irrigation systems. Harvesting, with 80 technologies, shows moderate progress in mechanisation and automation.

Compared to deep-tech technologies, the overall technological landscape covers a much broader application base across all stages. While deep-tech solutions dominate critical areas like crop cycle management and post-harvest logistics, traditional and intermediate technologies play a more significant role in stages such as sowing, pre-sowing, and harvesting. This suggests that deep-tech innovations, though impactful, are more concentrated in specialised areas, leaving considerable scope for their expansion in underdeveloped stages like sowing and harvesting. The broader adoption of traditional technologies indicates a need for bridging the gap between cutting-edge solutions and practical, scalable implementations for small and medium-scale farmers.

4.5.2 Mapping of technologies with challenges identified

We have also mapped various technologies to the challenges identified through a comprehensive survey of small farmers. This alignment allows us to better understand how specific innovations can address the pressing issues faced by the agricultural sector. For instance, technologies focused on crop monitoring and pest management were found to directly correlate with the challenges of pest infestations and yield variability, which were highlighted by farmers as significant concerns. Similarly, advancements in logistics and cold storage technologies were matched with the prevalent issue of post-harvest losses, as many farmers reported difficulties in maintaining the quality of their produce after harvest. By linking these technologies to the challenges outlined in our survey, we aim to provide a clearer roadmap for targeted interventions that can enhance agricultural practices and improve the livelihoods of small farmers. This strategic mapping not only identifies existing solutions but also pinpoints areas where further innovation is needed to tackle unresolved challenges in the agricultural landscape.



This graph illustrates the distribution of technological solutions mapped to the most prominent challenges faced by farmers in agriculture. It highlights both the prevalence of specific challenges and the corresponding technological interventions identified to address them.

Key Observations:

- **Market Issues (465 technologies):** Market-related challenges, such as access to fair pricing, transportation, and middlemen dependencies, emerged as the most critical area. The high number of technological solutions indicates a significant focus on addressing these challenges through platforms for price discovery, e-marketplaces, blockchain for traceability, and digital solutions connecting farmers directly with buyers.

- **Limited Access to Resources (344 technologies):** Challenges related to insufficient access to critical resources like fertilizers, seeds, and financial credit were the second most prominent. Technologies addressing this include mobile-based resource allocation systems, microfinance platforms, and soil-testing kits that optimize resource use.

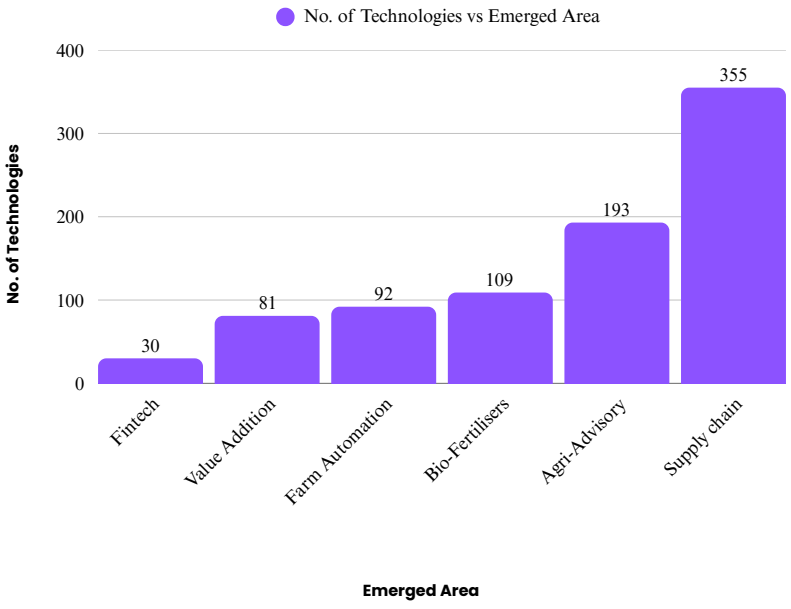
- **Lack of Knowledge and Training (210 technologies):** A considerable number of farmers cited the need for better knowledge and training to adopt modern farming practices. Solutions in this category include digital advisory services, training modules, and smartphone applications offering real-time guidance on crop management.

- **Technology and Innovation (206 technologies):** Although a slightly smaller number of solutions focus on introducing innovation and advanced technologies, they remain critical for transforming agricultural practices. These include precision agriculture tools, AI-driven pest monitoring systems, and IoT-enabled irrigation management.

- **Labour Shortage (30 technologies):** The limited focus on labor shortages may reflect the challenges of mechanization adoption by smallholder farmers. Available solutions include low-cost machinery, automation tools for harvesting, and AI-powered robotics, though further development is needed.

- **Stubble Burning (4 technologies):** Stubble burning has seen the least number of technological interventions, possibly due to its localized impact in specific regions. Current technologies address it through bio-decomposition, stubble reuse in biogas production, and incentives for zero-burn practices.

4.5.3 Mapping of technologies with emerging area



This graph illustrates the number of technologies mapped to various emerging areas in agriculture. The data provides insight into the focus of innovation and the alignment of technological advancements with evolving needs in the agricultural sector.

Key Observations:

- **Supply Chain (355 technologies):** Supply chain challenges dominate as the most addressed emerging area. Technologies in this domain focus on improving logistics, cold chain infrastructure, real-time inventory tracking, blockchain for traceability, and reducing post-harvest losses. These solutions aim to bridge the gap between production and market access, ensuring farmers receive fair prices and consumers access fresh produce.

- **Agri-Advisory Services (193 technologies):** A significant number of technologies focus on providing advisory services to farmers. These include mobile-based platforms offering real-time guidance on weather patterns, pest control, crop selection, and market pricing. Agri-advisory services are pivotal in enhancing decision-making and empowering farmers with actionable insights.

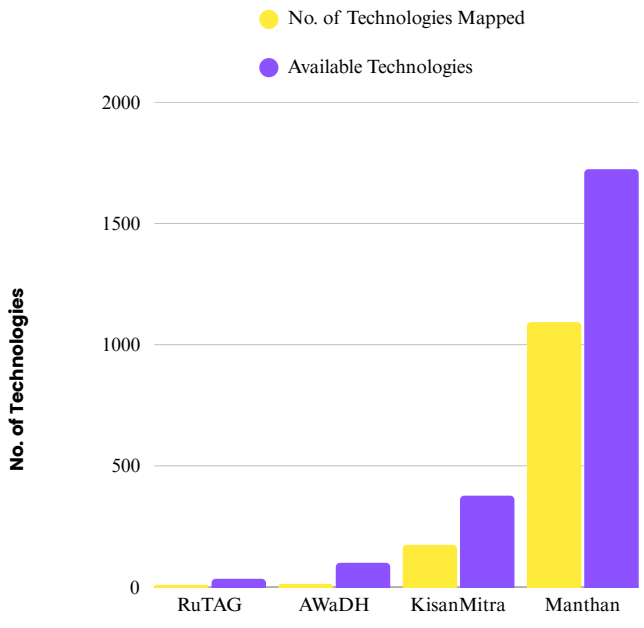
- **Bio-Fertilizers (109 technologies):** The development of bio-fertilizers is gaining momentum, reflecting the growing emphasis on sustainable farming practices. These technologies promote organic cultivation, improve soil health, and reduce dependence on chemical inputs, aligning with global trends toward eco-friendly agriculture.

- **Farm Automation (92 technologies):** Automation technologies are emerging as critical enablers of efficiency in agricultural operations. Solutions include mechanized sowing and harvesting tools, robotics for precision agriculture, and IoT-enabled equipment for monitoring crop health and resource optimization.

- **Value Addition (81 technologies):** Value addition technologies focus on post-harvest processing, packaging, and branding of agricultural produce. These solutions enable farmers to enhance the quality and marketability of their products, thereby increasing their income and competitiveness in global markets.

- **Fintech (30 technologies):** Fintech solutions, though limited in number, play a crucial role in facilitating access to credit, crop insurance, and financial literacy for farmers. Platforms leveraging AI for credit scoring and blockchain for secure transactions represent the growing potential of financial technologies in agriculture.

A robust matchmaking process was undertaken to map the available technologies across various platforms to specific agricultural challenges. Platforms such as Manthan, KisanMitra, AWaDH, and RuTAG were analyzed for their repositories of technologies. This exercise identified technologies suitable for addressing key challenges, ensuring that the potential of these platforms is leveraged effectively. For instance, the Manthan platform demonstrated the highest number of technologies mapped and available, showcasing its capability to contribute to diverse agricultural interventions.



No. of Technologies Mapped VS Available Technologies (By Platform)

Government Proposes Crop Diversification Linked to MSP

In 2024, the Indian government proposed linking the Minimum Support Price (MSP) to crop diversification, encouraging farmers to shift from traditional crops like rice and wheat to pulses, cotton, and maize.

Source: TIMES OF INDIA.INDIATIMES.COM

This mapping process not only aids in identifying relevant technologies but also fosters a collaborative approach among stakeholders, enabling better deployment strategies. By matching technologies to real-world challenges, these platforms can bridge gaps in adoption and application, making them more accessible to farmers and agribusinesses. Furthermore, the analysis highlights opportunities to expand utilization, especially for platforms like AWaDH and RuTAG, which have a smaller repository but significant untapped potential.

Such systematic matchmaking ensures that technologies are not merely stored in databases but are actively utilized to address pressing agricultural needs. This approach promotes synergies among platforms, encourages resource-sharing, and accelerates the implementation of solutions that can enhance productivity, sustainability, and resilience in the agricultural sector.

The available mapped technologies identified through this robust matchmaking process are documented in detail in the Google Sheet provided in Annexure 1. This sheet serves as a comprehensive resource, offering insights into the technologies available across platforms such as Manthan, KisanMitra, AWaDH, and RuTAG. It highlights their specific applications, mapped challenges, and potential areas for deployment.

This centralized documentation enables stakeholders to readily access and analyze the mapped technologies, facilitating informed decision-making. By providing a clear view of the available solutions, Annexure 1 serves as a critical tool to streamline the deployment process, encourage collaboration among stakeholders, and bridge the gap between technology repositories and practical applications in agriculture. This effort ensures transparency and maximizes the potential of existing technological resources.

Conclusion:

The survey findings, drawn from over 3.4 million farmers, provide compelling evidence of the systemic challenges that smallholder farmers in India face. The predominance of financial constraints (76.3%) and market-related challenges (75.6%) underscores the urgent need for a multi-pronged strategy to enhance credit accessibility, create equitable market linkages, and promote the adoption of advanced agricultural technologies. Addressing these challenges is essential for fostering a resilient and inclusive agricultural ecosystem.

A critical pathway to improving financial resilience is the expansion of institutional credit mechanisms, such as Kisan Credit Cards (KCC), microfinance initiatives, and digital lending platforms. Strengthening financial literacy programs and simplifying access to credit can empower smallholders to make strategic investments in quality inputs, modern equipment, and sustainable farming practices. Concurrently, leveraging digital marketplaces and e-commerce platforms will bridge the gap between farmers and buyers, ensuring price transparency, eliminating exploitative intermediaries, and optimizing supply chains.

Beyond financial and market access constraints, the survey reveals the pressing need to bridge the technology adoption gap. While innovations in precision agriculture, automation, and digital farming hold immense potential, their effective implementation remains a challenge for smallholders. Technology mapping initiatives—which facilitate direct engagement between farmers, research institutions, and agritech startups—are essential in ensuring that innovations are tailored to the unique challenges faced by small farms. In this regard, initiatives under the National Mission on Interdisciplinary Cyber-Physical Systems (NMICPS) and Technology Innovation Hubs (TIHs), such as AWaDH at IIT Ropar, serve as key enablers in driving the digital transformation of Indian agriculture.

AWaDH's pioneering efforts in developing cyber-physical technologies for agriculture—ranging from sensor-based monitoring systems to AI-driven advisory tools—demonstrate the transformative impact of integrating digital and physical resources. These solutions can enhance operational efficiency, reduce production costs, and mitigate environmental risks. However, the successful adoption of these technologies requires collaborative partnerships among farmers, policymakers, research institutions, and industry stakeholders. A concerted effort to build farmer-centric, scalable, and cost-effective digital solutions will ensure that smallholders are not only equipped to overcome present-day challenges but are also positioned to thrive in an evolving agricultural landscape.

In conclusion, the future of smallholder agriculture in India hinges on financial empowerment, market inclusivity, and technological advancement. By fostering an ecosystem that enables seamless credit access, strengthens digital market linkages, and promotes the adoption of next-generation farming solutions, policymakers and stakeholders can unlock the full potential of Indian agriculture. A sustained commitment to innovation and inclusivity will drive long-term growth, ensure food security, and empower millions of smallholder farmers, making Indian agriculture more resilient, competitive, and sustainable.

Policy Recommendations:

1. Establishment of a Centre of Excellence for Smallholding Farmers at IIT Ropar

The establishment of a Centre of Excellence (CoE) for smallholding farmers at IIT Ropar represents a strategic initiative to address the unique challenges faced by marginal and small-scale farmers in India. This CoE, developed in collaboration with the Office of the Principal Scientific Advisor to the Government of India, will leverage the expertise of IIT Ropar, local agricultural bodies, and technology innovators to create scalable solutions tailored to the needs of smallholders. The CoE will focus on three key areas: research, technology dissemination, and farmer capability enhancement. By conducting research into sustainable farming practices, piloting innovative technologies, and standardizing effective practices, the CoE will serve as a hub for developing and scaling solutions that can be implemented nationwide. For instance, it could focus on water management systems, soil health diagnostics, and post-harvest technologies—areas where small farmers face significant challenges. The CoE will also play a pivotal role in training farmers, equipping them with the skills needed to adopt modern techniques such as drip irrigation (currently adopted by only 22.79%) and advanced crop protection methods. By bridging the gap between research and implementation, the CoE will empower small farmers to enhance productivity, reduce input costs, and improve their livelihoods.

2. Focused Deployment of RuTAG and Lab Technologies for Small Farmers

The deployment of innovations developed by RuTAG (Rural Technology Action Group) and other research institutes is crucial for translating high-impact lab technologies into practical, farmer-friendly solutions. These technologies, which include water management systems, soil health diagnostics, seed selection tools, crop protection methods, and post-harvest solutions, must be made accessible at the farm level. For example, addressing the limited adoption of water-conservative irrigation techniques like drip irrigation (22.79%) and subsurface drip irrigation (4.41%) requires simplified and affordable solutions that small farmers can easily implement. Collaborative efforts with local agricultural organizations and farmer cooperatives will ensure maximum coverage and adoption of these technologies. By providing small farmers with access to tools that enhance productivity while reducing input costs, this initiative will help mitigate risks associated with farming. Furthermore, improved post-harvest technologies can significantly reduce losses, thereby enhancing marketability and profitability. This approach not only supports sustainable farming practices but also contributes to the economic resilience of smallholder farmers.

3. Village and Panchayat Level Technology Extension Centres

Establishing Technology Extension Centres at the village and panchayat levels is essential for creating a single-window support system for smallholding farmers. These centers will provide holistic support across the entire farming cycle—from pre-sowing to post-harvest stages. For instance, they can offer guidance on sourcing quality seeds (a challenge identified by 46.99% of farmers), soil management practices, crop planning, disease control, and post-harvest processing. Additionally, these centers will facilitate access to credit, government schemes, and market information, addressing critical gaps highlighted in the survey findings. By organizing training sessions, workshops, and demonstrations, the centers will enhance farmers' knowledge and encourage the adoption of new technologies. Linking these centers to internet platforms like KisanMitra will further streamline access to updated information on technology, government initiatives, and market trends. Such an integrated approach ensures that small farmers receive timely and relevant support, empowering them to make informed decisions and adopt best practices. This initiative will play a vital role in strengthening the resilience and sustainability of smallholder farming communities.

4. Enhancing Access to Essential Resources

Improving access to essential resources such as irrigation infrastructure, quality seeds, and credit is fundamental to supporting small farmers. Given that 62.50% of farmers rely on flood irrigation—a method that is inefficient and water-intensive—promoting water-conservative techniques like drip and subsurface drip irrigation is critical. Training programs and subsidies can encourage wider adoption of these methods, conserving water while boosting yields. Similarly, addressing the challenge of sourcing quality seeds, which influences crop selection for 46.99% of farmers, requires establishing reliable supply chains and promoting seed certification programs. Ensuring adequate and timely credit is equally important, as it enables farmers to invest in quality inputs, modern equipment, and advanced farming practices. By improving access to these resources, policymakers can empower small farmers to overcome barriers to productivity and sustainability, ultimately enhancing their livelihoods.

5. Strengthening Market Linkages

Connecting smallholders to reliable markets is essential for ensuring fair prices and reducing post-harvest losses. With 75.6% of respondents identifying market access as a significant challenge, establishing effective market channels is a priority. Promoting value addition and processing through investments in post-harvest technologies can improve the quality and shelf life of agricultural produce, making it more marketable. Leveraging digital marketplaces offers another promising avenue, bridging the gap between small farmers and wider markets. These platforms can provide real-time information on demand, pricing, and logistics, enabling farmers to sell their produce directly to buyers. By strengthening market linkages, policymakers can ensure that small farmers receive fair compensation for their efforts, thereby improving their income and incentivizing sustainable practices.

6. Expanding Training and Knowledge Dissemination

Tailored training programs and workshops are vital for equipping small farmers with the skills and knowledge needed to adopt advanced farming practices. These programs should focus on efficient irrigation techniques, modern technologies, and sustainable farming methods. Establishing extension centers linked to platforms like KisanMitra can provide continuous support and updates on government schemes and market trends. Farmer-centric technology transfer, which simplifies and tailors solutions to the specific needs of smallholders, can further promote adoption. For example, training on the use of soil health diagnostics and crop protection methods can help farmers optimize resource use and minimize risks. By fostering a culture of learning and innovation, these initiatives will empower small farmers to enhance productivity and build resilience against climate change and market fluctuations.

7. Fostering Innovation and Technology Adoption

Encouraging public-private partnerships and supporting technology innovation hubs (TIHs) like AWaDH can accelerate the development and deployment of innovative solutions for smallholders. A dedicated CoE at IIT Ropar can drive research and pilot projects that address the unique needs of small farmers, such as water management and post-harvest technologies. By fostering collaborations between research institutions, startups, and the agricultural sector, these initiatives can create a thriving ecosystem of technology-driven solutions. For instance, innovations in seed selection tools and efficient irrigation systems can significantly benefit small farmers by reducing costs and improving yields. Continued support for such initiatives will ensure that smallholders have access to cutting-edge technologies, enabling them to compete in a rapidly evolving agricultural landscape.

8. Enhancing Access to Credit

Access to affordable and timely credit is a critical enabler for smallholder farmers, allowing them to invest in quality inputs, modern equipment, and advanced farming practices. However, many small farmers face significant barriers in accessing formal credit due to limited financial literacy, lack of collateral, and insufficient outreach of banking systems. To address these challenges, policymakers should focus on expanding institutional credit mechanisms such as Kisan Credit Cards (KCC) and microfinance initiatives, while simplifying application processes to make them more farmer-friendly. Additionally, integrating credit access with digital platforms can streamline disbursement and repayment processes, ensuring transparency and convenience for farmers. For example, linking credit facilities to mobile banking apps or digital wallets can enable farmers to apply for loans, track their usage, and repay installments seamlessly. Specialized financial products tailored to the needs of smallholders—such as crop-specific loans or weather-indexed insurance—can further mitigate risks associated with farming. By improving access to credit, policymakers can empower small farmers to overcome financial constraints, adopt sustainable practices, and enhance productivity.

9. Leveraging Digital Marketplaces

Digital marketplaces offer a transformative solution to the longstanding challenge of market access faced by smallholder farmers. With 75.6% of respondents identifying market access as a significant issue, bridging the gap between farmers and buyers is essential for ensuring fair prices and reducing dependency on exploitative intermediaries. Digital platforms can provide real-time information on market demand, pricing trends, and logistics, enabling farmers to make informed decisions about when and where to sell their produce. For instance, integrating digital marketplaces with Farmer Producer Organizations (FPOs) can facilitate collective bargaining, allowing smallholders to negotiate better prices and access larger markets. These platforms can also connect farmers directly to consumers, retailers, and exporters, eliminating middlemen and increasing profit margins. Additionally, features like e-commerce integration and online payment systems can further simplify transactions, ensuring timely payments and reducing financial risks. By promoting the adoption of digital marketplaces, policymakers can create a more equitable and efficient agricultural value chain, empowering small farmers to compete in both domestic and global markets.

10. Promoting Processing and Value Addition

Post-harvest losses remain a significant challenge for smallholder farmers, with a substantial portion of agricultural produce being wasted due to inadequate storage and processing facilities. Promoting value addition and processing is therefore critical to enhancing the marketability and profitability of farm produce. Investments in decentralized processing units at the village or cluster level can help farmers preserve their crops, extend shelf life, and fetch higher prices. For example, perishable crops like fruits and vegetables can be converted into value-added products such as jams, pickles, dried fruits, or frozen items, which have longer shelf lives and higher market value. Similarly, grains and pulses can be processed into ready-to-cook formats or packaged under branded labels to tap into premium markets. Training programs on food safety standards, branding, and packaging can further equip farmers to meet consumer demands and access urban or export markets. Moreover, promoting collective processing initiatives through Farmer Producer Organizations (FPOs) can enable smallholders to pool resources and share costs, making value addition more feasible and profitable. By focusing on processing and value addition, policymakers can help farmers reduce post-harvest losses, increase income, and build resilience against market fluctuations.

Annexure:

1- Questionnaire on ground Survey

2- Questionnaire online Survey

3- Technology Mapping Spreadsheet

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