



# Agriscope

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## Social Media for Information Dissemination in Agricultural Education

Sabita Mondal<sup>1</sup>, Arindam Sarkar<sup>2</sup>, Debalina Debnath<sup>3</sup>, Pushpita Sarkar<sup>4</sup>

<sup>1</sup>Assistant Professor, Department of Agricultural Extension, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal

<sup>2,3,4</sup>Research Scholars, Department of Agricultural Extension, Uttar Banga Krishi Viswavidyalaya, Pundibari, Coochbehar, West Bengal

Corresponding author's email ID: [sabidas\\_2007@rediffmail.com](mailto:sabidas_2007@rediffmail.com)

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The word education is derived from Latin words, i.e., 'educare' and 'educatum'. Educare means 'to train and mould', whereas educatum is 'the act of teaching'. It is a continuous and lifelong process of acquisition of experiences that leads to the development of both an individual and society, in such a manner that both find happiness and prosperity. Earlier, it has a traditional system of face-to-face education. However, with the invention of the internet, different social media platforms have been developed and have become an integral part of our lives. Learners at all levels and spheres are preferring to use social media to access, learn and share ready information, reviews and solutions for their queries. It has become the fastest communication channel used by people globally for sharing information within a fraction of a second.

Initially, social media was developed and considered to be a method of communication among friends, family and known people. Its content may include a pool of information, starting from personal information, documents, videos, photos, blogs, podcasts, micro-blogs, weblogs, business forums, etc. Users can get engaged with social media through computers, tablets, smartphones, provided with internet facility, via web-based software, etc. Later, people started using various social media applications for networking and finding career opportunities. It has connected billions of people across the globe and facilitated the sharing of their thoughts, feelings and insights through the virtual network. At present, it has become an irreplaceable tool not only in the field of communication and marketing but also in education.

Social media is helping people to connect with different learning groups and educational systems and thus has made education much more convenient. Over the period of time, social network tools and techniques have immensely improved the learning methods. Moreover, social media plugins have enabled the sharing and interaction among millions of people across the globe. Learners all over the globe are benefitting from online tutorials and study materials, shared through various social

networking sites. Several social media sites have made it possible.

### **Types of social media**

Social media includes multiple tech-enabled activities like photo sharing, blogging, social gaming, social networks, video sharing, business networks, virtual worlds, reviews, and much more. Different platforms can be used in various ways in the field of education. Some of the possible ways are explained as follows.

#### **Facebook Page for updates**

Facebook can be treated as an extended classroom for communicating updates. It can be a perfect social media platform. Instead of introducing the instructors and learners to a new application, sticking to something which everyone is already aware of and accustomed to may improve the acceptability. Learners may be encouraged to follow the classroom's Facebook Page, where the class updates, details of homework, assignments, group discussion, etc., would be posted. In the case of agricultural education, there is a wide section of people who would be interested to learn about the updates. A different Facebook page, including updates in a layman's language, would benefit people who are in need of such information.

#### **Facebook Group for discussions**

A Facebook Group can be created by the instructors/mentors for every class. It can be open to both public or private. This platform can be used for streaming of live lectures, post-discussion, question and answer sessions, awareness creation, assigning homework and making important announcements. This can help the instructors to keep the learners engaged during summer, winter and other such holidays by posting reminders regarding holiday assignments and evaluating the same before school reopens. However, the use of social media for education should be more formal, with professional boundaries set by the educational institutions. In the process of creation of the Facebook group for the learners, the instructor/mentor should not send friend's request to the learners instead a direct link of the Facebook Group for access to be send to the registered E-mail of both parents as well as the learner.

#### **Twitter as Message Board**

Twitter, a very popular social media tool, can be used exactly like a discussion board or message board for the learners as well as their parents. A single Twitter handle can be created by instructors for each class and the same can be reused every year, or a separate handle can be created for each

academic session. The character limit of 280 would make the students think critically and communicate effectively and precisely. Instructors can also use Twitter to put reminders for the assignment/project submission due date. Inspirational quotes, motivational messages and helpful links for quizzes or study materials can also be posted or shared. Instructors can also motivate the learners for discussions via Twitter chats on some specific topics like sustainable agriculture, climate-smart farming, increasing farmers' income, women empowerment, etc.

### **Instagram for Photo Essays**

Instagram can be used by the learners to put photographs and graphics in a visually appealing and meaningful manner to spread important messages in a colorful and eye-catching manner. It would develop the skill of digital storytelling among learners. Learners may be encouraged to create class-specific Instagram accounts and these may be deleted after the course is completed.

### **Blog for Discussions**

Blog writing may be an alternative available for learners. Writing blog posts builds creativity among the learners and helps in brainstorming. There are various platforms available, such as WordPress, Squarespace, WIX, Blogger, Tumblr, or Medium, where both instructor and learner can create a blog specific to the class. Learners may also create their own user accounts to add posts or add comments on the posts. The blog can also be used to put updates on syllabus, practicals etc.

### **Blog Posts for write-ups**

Learners may create their own blog for writing essays, articles, success stories, etc., which can be a strategy for connecting social media with learning. This type of writing would develop students' writing and presentation skills. The platform may not be limited just to the writing skills of the student, but may also be used to share their innovative idea and concepts. It may also be a place to post the researchable areas for further discussion, like natural farming, climate-smart agriculture, etc.

### **Subject-Specific Pinterest Board**

Instructors may design Pinterest boards for each of their discussions and save pins to the relevant information. Pinterest is a great social media platform for instructors to prepare and organize resources, lesson plans and worksheets for their content in one place. Create boards according to the learner's group or subject, and create sub-topic boards for weekly tasks or other assignments.

### **Social Media Links on institution Website**

Adding social media links on websites makes it easier for the learners and various stakeholders to get the institution's social media profiles by visiting the website. A social media directory may also be developed that houses them all in one place.

### **Share Institution's Achievements and Events**

In order to spread awareness and disseminate information, photos of various events, activities and achievements happening in the institution may be shared for all interested stakeholders. This would keep people informed and educated.

### **Interest-based Facebook Groups**

Creating an interest-based Facebook group for all learners, instructors, officials and stakeholders can keep everyone informed and educate them. It would provide motivation as well as guidance to the learners staying on the campus and stakeholders present off the campus. It would also bring all interested learners under one single umbrella.

### **Role of Social Media in Agricultural Education**

Agricultural education is a part of the curriculum for many primary and secondary schools, along with tertiary institutions like colleges, universities, vocational and technical schools. Agricultural education resources are being provided by youth organizations, farm apprenticeships/internships, different non-profit organizations, and various government agencies/ministries. This is also being done by agricultural workshops, trainings, shows, fairs and research institutions. It is a vast subject, consists of unlimited information. There is always new information, ideas, innovations, techniques, and tools to be learned. This requires constantly updated information. Thus, a pre-fixed course curriculum and a set of instructors are not sufficient to disseminate all the required information all the time. Thus, social media may play a vital role in the dissemination of information as well as the running of the institution efficiently and effectively.

Social media provides a very unique characteristic of self-paced learning, where the information/ content can be accessed by the learners from any place and at any time, as per their convenience. It provides them with an opportunity to interact and learn from others, irrespective of the geographical location. It helps them in developing, computing and communication skills as well as acts as a faster medium of disseminating required in need and on specific problems/topics. It also enhances learners' participation, interaction, insights and writing skills (Zheng, 2013).

Social media also enhances instructor-learner relationships and serves as a forum for

interaction (Williams, 2012) and provides opportunities for collaborative learning. (Lockyer and Patterson, 2008). Its user-friendly nature creates an inclusive learning environment for learners, even learners with special abilities, who experience similar learning using social media (Asuncion *et al.*, 2012).

### **Challenges of Social Media Use in Education**

Young learners face multiple challenges due to this association with social media for education. They face issues like threats to privacy, health, misguidance, wrong or incorrect information, etc. People get addicted to social networking sites like Facebook, Twitter, WhatsApp, Instagram, etc. Young learners make friends with strangers and share personal information with them. These types of associations were many times found to be a threat to their mental health. Spending a lot of time on online education has also created problems like social isolation among students as well as with their instructors/mentors.

### **Negative Impacts of Social Media Use in Education**

The first and foremost ill effect of social media is addiction to the virtual world. People get habituated to checking their accounts on Facebook, Twitter, LinkedIn, WhatsApp, etc. after every few mins. It becomes a reason for distraction and lack of concentration. With the passage of time, people stop taking an active part in socializing in person, taking part in sports, communication, etc. It reduces the focus and retention power of learners. They tend to rely more on social media and other websites for getting answers to queries, as this requires less time and the information is accessible in no time. They don't want to spend more time searching for things on their own. People who spend more time on social media slowly reduces their communication and feel more comfortable in communication using social media.

### **Conclusion**

Social media is playing a very important role in the field of education. With its help, accessing information and communicating with instructors, colleagues and other people of the same interest group have become very easy. Learners can now remain connected to their peers all the time using this platform. However, the use of social media for education has some disadvantages also and therefore, has been criticized of late. Thus, social media tools must be regulated by the instructors or the mentors at the institutional level and access should be allowed as per the age of the learners. People must be sensitized regarding the negative aspects or ill effects of social media. Instructors and mentors must be skilled and technically sound about the use of different sites, settings and their

functions. They need to be aware of the various risks involved in it and must protect the young minds from this.

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## Reviving the Loom: KRDP's Role in Strengthening Khadi in Chhattisgarh

<sup>1</sup>Eshant Kumar Sukdeve and <sup>2</sup>Hem Prakash Verma

<sup>1</sup>PhD, Agricultural Extension, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.)

<sup>2</sup>Senior Research Fellow, FFP Project, ICAR-National Institute of Biotic Stress Management, Baronda, Raipur (C.G.)

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### Abstract

The Khadi Reform and Development Programme (KRDP), initiated with the support of the Asian Development Bank (ADB) and the Government of India, represents a transformative intervention for the Khadi and Village Industries (KVI) sector in India. The programme aims to modernize production systems, enhance livelihood opportunities, and revitalize traditional craftsmanship. This article examines the socio-economic impact of KRDP on weavers in Chhattisgarh, drawing on insights from the study conducted across various districts. The programme has strengthened livelihood security through improved wages, infrastructure development, skill enhancement, market linkages, and entrepreneurial support. By integrating policy reforms, marketing interventions, institutional restructuring, and technological upgrades, KRDP has significantly contributed to raising the income levels, working conditions, and economic resilience of weavers in the state.

### Introduction

Village and Small Industries (VSI) have always held a strategic position in India's economic framework, providing the second-largest source of employment after agriculture. Traditional sectors such as handloom, handicrafts, coir, sericulture, and khadi continue to shape rural livelihoods and preserve India's craft heritage. Khadi and Village Industries (KVI) represent a crucial segment of this unorganized, non-factory sector, generating employment at minimal capital cost and utilizing local skills and raw materials.

Historically, khadi emerged as both an economic and symbolic force under Mahatma Gandhi during India's struggle for independence. Before 1947, it functioned as a non-governmental movement rooted in self-reliance and rural empowerment. Post-independence, the government institutionalized khadi development through the establishment of the Khadi and Village Industries Commission (KVIC) in 1956, which became the nodal agency for promoting and supporting khadi production through state-level boards (KVIBs).

To address modern challenges ranging from outdated production systems to limited market competitiveness, the Khadi Reform and Development Programme (KRDP) was launched. In 2008, ADB approved a USD 150 million loan to support comprehensive reforms, including policy restructuring, institutional strengthening, marketing upgrades, and modernization of khadi production systems. The programme sought to position khadi in alignment with contemporary market needs while enhancing wages, employment generation, and artisan empowerment.

In Chhattisgarh, home to a rich weaving tradition, KRDP has played a catalytic role. The programme's interventions, like skill development, infrastructure upgrades, marketing support, financial assistance, and cluster development, have collectively contributed to improving the livelihoods of weavers. Enhanced income stability, increased market visibility, adoption of innovative designs, and improved working conditions have supported both socio-economic progress and cultural preservation. These efforts have empowered weavers not only as skilled artisans but also as emerging entrepreneurs capable of participating in national and global textile markets.

### **Strengthening Traditional Craft through Modern Interventions**

Chhattisgarh's weaving heritage reflects centuries of indigenous knowledge, artistry, and cultural identity. However, many artisans historically faced challenges such as outdated tools, low market penetration, and limited opportunities for skill enhancement. KRDP has helped bridge this gap by integrating traditional wisdom with contemporary techniques. The programme's training modules focus on advanced weaving skills, improved yarn handling, natural dyeing methods, design innovation, and quality enhancement. By enabling artisans to adopt modern techniques without losing cultural authenticity, KRDP ensures that traditional craft continues to flourish in a globalized market. These initiatives have not only improved product consistency and durability but have also allowed weavers to create textiles that appeal to diverse consumer segments—from domestic buyers to international design houses. The infusion of modern design sensibilities has opened new avenues for khadi, positioning it as both a heritage fabric and a sustainable, eco-friendly fashion choice.

### **Infrastructure Development and Market Expansion**

One of the longstanding barriers for weavers in Chhattisgarh was the absence of adequate infrastructure. KRDP has addressed this challenge by establishing Common Facility Centres (CFCs) equipped with improved looms, dyeing units, quality testing facilities, and finishing tools. These centers serve as shared spaces that reduce the cost burden on individual artisans while increasing efficiency and output quality.

Additionally, modern weaving sheds with better ventilation, lighting, and ergonomically

designed equipment have markedly improved the working environment. These improvements have resulted in enhanced productivity, reduced physical strain, and greater consistency in production.

On the marketing front, KRDP has made significant strides by strengthening linkages with urban markets, retail chains, exhibitions, and digital platforms. With the introduction of the Khadi Mark, consumers now have an assurance of quality and authenticity, which has further boosted product credibility. Social media promotion, participation in national trade fairs, and collaborations with fashion designers have increased the visibility and desirability of Chhattisgarh's khadi products, thereby ensuring stable demand throughout the year.

### **Institutional Strengthening and Policy Interventions**

KRDP is not just a skill development initiative; it is a holistic reform programme aimed at revitalizing the entire khadi ecosystem. The restructuring of the Khadi and Village Industries Commission (KVIC) has played a critical role in strengthening governance, planning, and service delivery. The programme emphasizes:

- Transparent financial management
- Streamlined raw material supply chains
- Credit facilitation through banks and government schemes
- Upgradation of institutional record-keeping and monitoring systems

These policy interventions ensure that assistance reaches the grassroots and that institutions remain accountable, efficient, and responsive to artisan needs. The strengthening of cooperative societies has also empowered weavers to bargain collectively, participate in decision-making processes, and access benefits equitably.

### **Enhancing Livelihoods and Promoting Entrepreneurial Culture**

One of the most transformative outcomes of KRDP is the shift from wage-based labour to entrepreneurial engagement. Many weavers who previously depended solely on daily wage earnings are now running small enterprises, managing production groups, and marketing their own products. Training on financial literacy, branding, packaging, and digital marketing has given artisans the confidence and capacity to manage their enterprises efficiently.

Women weavers, in particular, have significantly benefited. KRDP has enabled them to gain financial independence, assume leadership roles in cooperatives, and achieve greater social recognition. This empowerment has not only enhanced household income but also contributed to improved education, health, and well-being of their families.

## **Sustainable Development and Future Scope**

KRDP's alignment with sustainable, eco-friendly production practices positions it strongly within the global demand for ethical textiles. The use of natural fibers, biodegradable dyes, and hand-based processes reduces carbon footprint and makes khadi a sustainable choice. This opens opportunities for exports, design collaborations, and niche luxury markets.

Looking ahead, integrating khadi with e-commerce, developing youth-centric training programmes, and establishing design innovation hubs in Chhattisgarh can further strengthen the sector. Strengthening partnerships among government agencies, private designers, NGOs, and academic institutions will create a more resilient ecosystem for artisanal growth. With continued support, Chhattisgarh has the potential to become a national model for rural textile-based entrepreneurship and sustainable craft revival.

Chhattisgarh's weaving sector, enriched by generations of traditional hand-spinning and weaving artistry, has received a significant boost through the interventions of the Khadi Reform and Development Programme (KRDP). By integrating heritage skills with modern techniques, KRDP has strengthened artisans' capabilities through skill enhancement, design innovation, and training in contemporary weaving methods, enabling the production of superior-quality and market-responsive fabrics. The establishment of Common Facility Centres, upgraded weaving sheds, and improved dyeing, printing, and finishing units has addressed long-standing infrastructural challenges while expanding market access through exhibitions, trade fairs, and digital platforms that have substantially increased the visibility of Chhattisgarh's khadi. These systemic improvements have translated into better livelihood security, with weavers reporting higher and more stable incomes due to streamlined raw material procurement, financial support, and cooperative mechanisms that ensure fair wages and transparency. Beyond income enhancement, KRDP has nurtured a culture of entrepreneurship, empowering artisans to evolve from wage workers into micro-entrepreneurs skilled in branding, quality control, and marketing. Notably, the programme has had a transformative social impact by elevating the status of women weavers, providing them with financial independence, leadership opportunities in cooperative structures, and enhanced roles within their households and communities, thereby contributing to both socio-economic resilience and the revitalization of Chhattisgarh's weaving heritage.

## **Conclusion**

The Khadi Reform and Development Programme (KRDP) has demonstrated a substantial positive impact on the socio-economic well-being of weavers in Chhattisgarh. Through

comprehensive reform measures including training, improved infrastructure, financial support, marketing initiatives, cluster-based development, and institutional restructuring, the programme has significantly enhanced productivity, income, and livelihood resilience among weaving communities. Weavers now benefit from better access to raw materials, modernized production facilities, expanded market reach, and opportunities for entrepreneurship.

Moreover, KRDP has played an essential role in preserving traditional weaving techniques while integrating innovation to meet contemporary consumer preferences. The enhanced visibility of Chhattisgarh's khadi products at national and global platforms has further strengthened market confidence and artisan recognition. Despite certain limitations in data collection and geographical coverage noted in the original study, the overall outcomes highlight KRDP as a transformative initiative capable of fostering sustainable rural development. Continued policy support, investment in design innovation, and stronger digital marketing linkages will be critical in ensuring the long-term growth and competitiveness of the khadi sector in Chhattisgarh.

## Bridging the Gap: Designing and Deploying Mobile-Based Horticultural Advisory Services

<sup>1</sup>Abhay Thakur, <sup>2</sup>Kshitiz Sood, <sup>1</sup>Anjali Devi, <sup>1</sup>Harshul Jamwal

<sup>1</sup>M.Sc. Student, Agricultural Extension Education, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

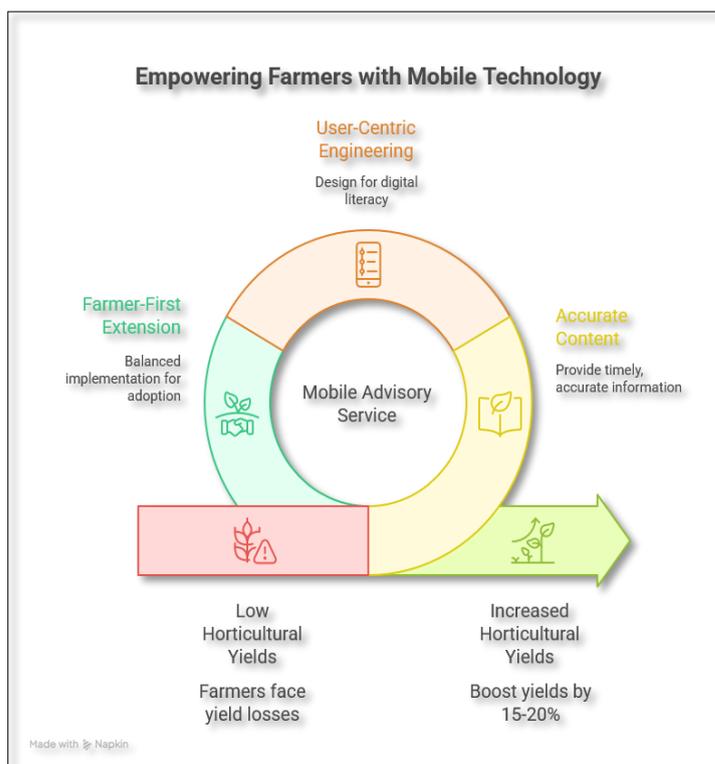
<sup>2</sup>B.Tech. CSE Student, Department of Computer Science and Engineering, Chandigarh University, Punjab, India

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### 1. INTRODUCTION

In India, the horticulture sector has emerged as a key driver of agricultural growth, contributing approximately 33 per cent to the agricultural Gross Value Added (GVA) and supporting nutritional security for millions. However, high-value horticultural crops such as fruits, vegetables, and spices are also high-risk. Farmers face challenges, including climate variability, soil health degradation, and, devastating pests and diseases, which can cause 20-40 per cent yield losses in crops like tomatoes. The core problem is often not a complete lack of information, but a lack of timely, accurate, and personalized information that can empower a farmer to act.

While India's traditional agricultural extension system provides essential guidance, its agents are often stretched thin, with a low agent-to-farmer ratio making personalized, real-time guidance a logistical impossibility. Research suggests that mobile technology can help bridge this information gap, though success varies due to barriers like digital literacy and connectivity. This article argues that effective mobile-based advisory service depends not just on the technology itself, but on a perfect



synergy of three components: accurate horticultural content (the 'what'), user-centric engineering (the 'how'), and a farmer-first extension strategy (the 'adoption'). However, evidence indicates that while such apps can boost yields by 15-20 per cent, adoption rates remain low in some regions, highlighting the need for balanced implementation.

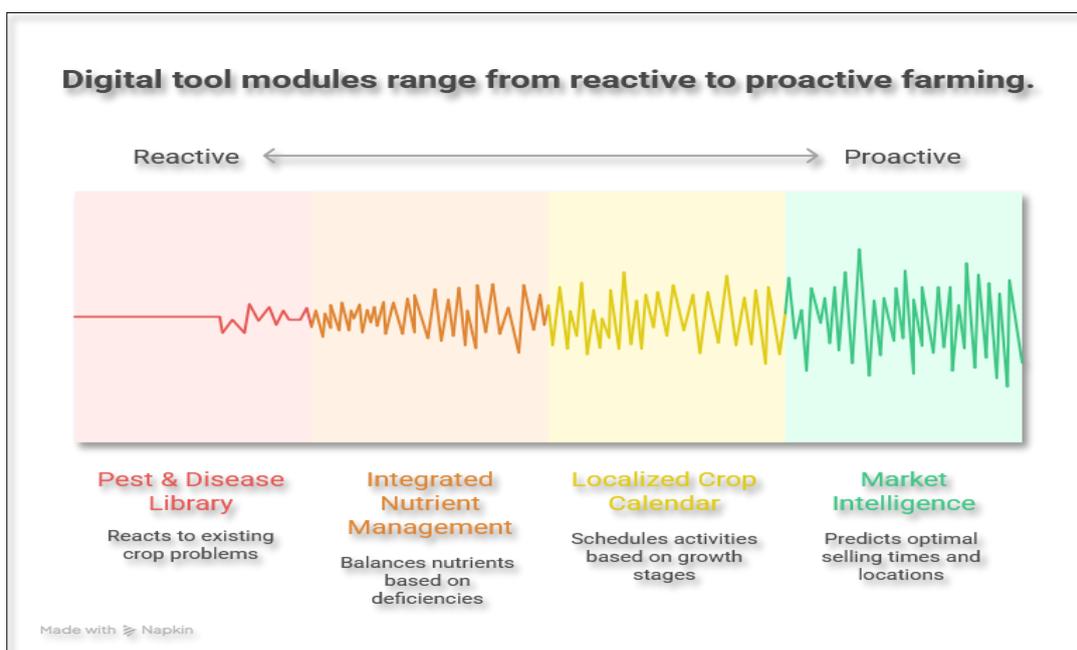
## 2. THE 'WHAT': BUILDING THE HORTICULTURAL KNOWLEDGE BASE

The foundation of a successful digital tool is scientifically sound, practical, and locally relevant content. Studies show that tailored advisories can reduce pesticide use by up to 9 per cent and improve decision-making.

Using tomato as an example, essential modules include:

- **A Localized Crop Calendar:** A dynamic, GPS-based schedule for nursery raising, transplanting, irrigation, and fertigation (drip irrigation) based on regional growth stages.
- **A Visual Pest & Disease Library:** Farmers identify problems visually, not by scientific names. High-resolution photo library of common issues like common diseases, e.g., Tomato Leaf Curl Virus, Early Blight, Buckeye Rot and pests such as *Helicoverpa armigera* (Tomato Fruit Borer), *Liriomyza trifolii* (Serpentine leaf miner), *Bemisia tabaci* (Whitefly), linked to clear, actionable Integrated Pest Management (IPM) steps, prioritizing cultural and biological methods before chemical ones.
- **Integrated Nutrient Management (INM):** The app should provide simple, visual guides for identifying nutrient deficiencies (e.g., yellowing leaves for nitrogen, blossom-end rot for calcium in tomatoes). It can further recommend soil-test-based fertilizer applications, promoting balanced fertilization over the indiscriminate use of urea.
- **Market Intelligence:** A simple but powerful feature is the integration of real-time mandi (market) prices from nearby locations, which can increase farmer incomes by 5-12 per cent. This empowers farmers with price transparency, enhancing their bargaining power and helping them decide the optimal time and place to sell their produce.

To broaden applicability, similar modules can apply to other crops like potatoes (focusing on storage tips and diseases like late blight and wart) or spices (emphasizing export standards and market trends).

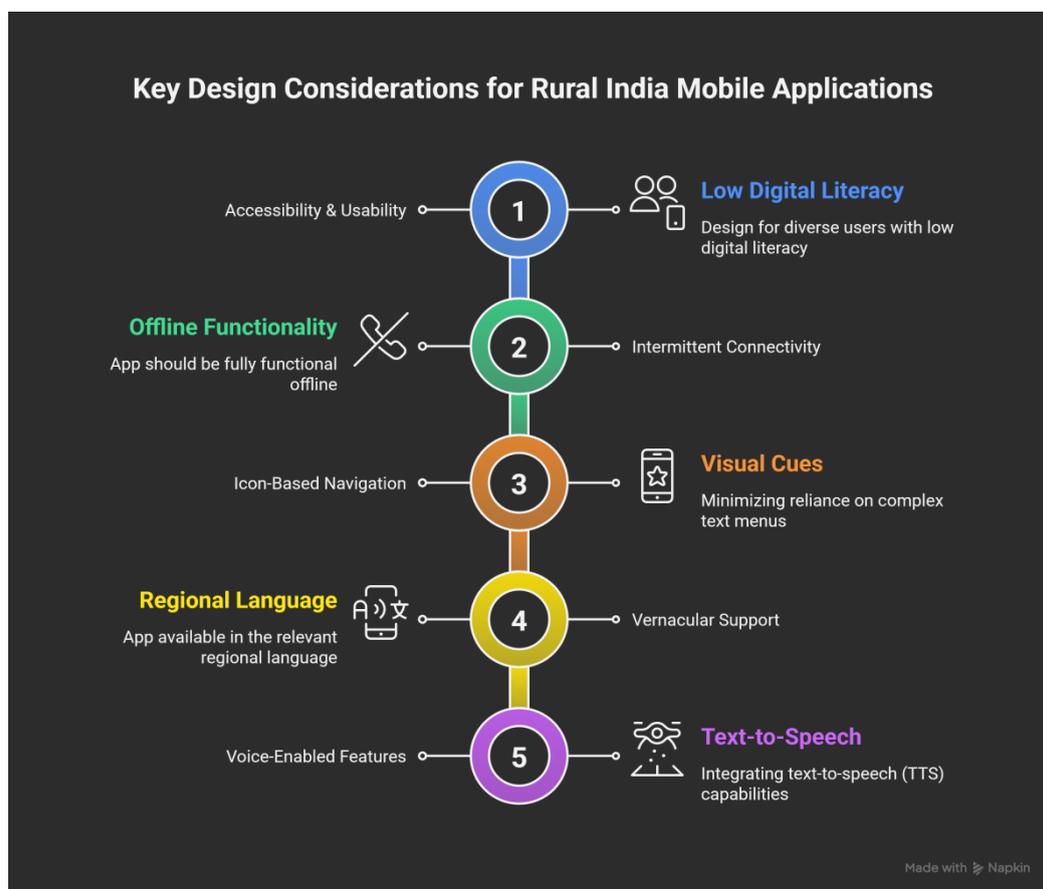


### 3. THE 'HOW' (PART A): DESIGNING FOR THE FARMER, NOT THE ENGINEER

From a computer science and engineering perspective, the primary challenge in designing for rural India is not implementing complex AI, but ensuring accessibility, reliability, and usability for a diverse users with low digital literacy, entry-level smartphones and intermittent connectivity. With rural mobile penetration at around 59 per cent and internet access at 55 per cent, design must address these realities. Core principles include:

- **'Offline-First' Architecture:** The app cannot be a simple web portal that requires a constant 3G or 4G connection. Core content like the pest library, crop schedules, and guides must be stored locally on the phone's memory, perhaps in a lightweight database like 'SQLite', etc. The app should be fully functional offline and only require an internet connection to sync new updates, weather data, or market prices.
- **Icon-Based UI/UX (User Interface/User Experience):** Navigation must be intuitive and visual, minimizing the reliance on complex text menus. The user interface (UI) should be driven by large, universally understood icons a 'leaf' for diseases, a 'rupee symbol' for prices, a 'calendar' for tasks. This makes the app navigable even for users with low literacy levels.
- **Vernacular and Voice-Enabled:** The app must be available in the relevant regional language, such as Hindi, Punjabi, Marathi, etc. Furthermore, integrating text-to-speech (TTS) capabilities is a crucial feature. A farmer who struggles to read can simply press a button to have the advisory read aloud in a clear, local voice, bridging the literacy gap entirely.

Development costs can exceed \$50,000, so open-source tools should be considered for scalability. Additionally, integrate emerging AI for image-based pest identification, achieving 80-90 per cent accuracy in apps like Plantix. Address equity by designing for gender differences, as women farmers often face higher barriers to tech access.



#### 4. THE 'HOW' (PART B): THE EXTENSION STRATEGY FOR TRUST AND ADOPTION

Developing a technically sound, content-rich app is only half the battle. The agricultural extension challenge, getting farmers to download, trust, and consistently use it, is where most digital initiatives fail. A 'launch it and they will come' approach is doomed. While apps like BharatAgri and RML AgTech have reached thousands, overall retention can be under 30 per cent due to trust and connectivity issues. A successful adoption strategy must be human-centric:

- **The 'Phygital' (Physical + Digital) Model:** The app should not, and cannot, replace the extension agent. It must empower them. Farmers trust people, not pixels. The app's credibility is established when it is introduced by a trusted local figure, the scientist at the Krishi Vigyan Kendra (KVK), the local Agricultural Officer, or the Block Technology Manager (BTM) from

the ATMA scheme. The app becomes a tool the agent uses with the farmer, blending physical trust with digital efficiency.

- **Training the Trainer:** We cannot train 10,000 individual farmers. The extension model must be a 'Training the Trainer' cascade. A small team trains 100 extension agents and 500 'Lead Farmers'- progressive, respected members of the community. These trained individuals then become local champions, demonstrating the app to their peer groups, in FPO (Farmer Producer Organisation) meetings, and at demonstration plots. This builds social proof and creates a local support network.
- **A 'Push-Pull' Information System:** The app must serve two functions. First, it allows the farmer to 'pull' information whenever they need it (e.g., "What is this spot on my leaf?"). Second, it allows the extension service to 'push' critical, time-sensitive alerts to all users in a specific geographical area. For example, a "push notification" warning of an impending pest outbreak based on weather patterns (e.g., "High humidity predicted, high risk of Downy Mildew in your block") or an alert for a government subsidy application deadline.

Policy integration with schemes like MIDH can enhance reach, but challenges like the digital gender divide must be addressed to include women farmers.

## 5. CONCLUSION

Mobile technology is a powerful enabler, but it is not a silver bullet. The future of a profitable and resilient Indian horticulture sector lies in an interdisciplinary synergy. Real-world impact is created only when accurate horticultural science, intuitive and robust computer engineering, and a human-centric, trust-based agricultural extension strategy converge. Research suggests integrated approaches yield mixed results, with successes in yield gains offset by adoption barriers. This integrated 'phygital' approach is the key to successfully bridging the information gap and empowering every farmer with the knowledge they need, right in their pocket. Future trends include AI-enhanced features and IoT for real-time monitoring, as seen in government pest detection schemes. Piloting apps with KVKs and evaluating impacts through farmer surveys is recommended to refine these tools.

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## Hidden Harvests: Unlocking the Potential of Neglected and Underutilized Vegetable Species (NUVS)

Abika Chauhan<sup>1\*</sup>, Harsh Pathania<sup>1</sup> and Abhay Thakur<sup>2</sup>

<sup>1</sup>M.Sc. Student, Department of Vegetable Science, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

<sup>2</sup>M.Sc. Student, Agricultural Extension Education, COHF, Neri, Dr. YSPUHF, Nauni, Solan, Himachal Pradesh, India

\*<sup>1</sup>Corresponding author email- [abikachauhan28@gmail.com](mailto:abikachauhan28@gmail.com)

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### Abstract

*As the global population surges towards 9 billion, the dual challenges of climate change and "hidden hunger" (micronutrient malnutrition) loom large. Modern agriculture, with its over-reliance on a narrow basket of staple crops, has inadvertently marginalized a treasure trove of biodiversity (FAO, 2024). This article explores the untapped potential of Neglected and Underutilized Vegetable Species (NUVS). By synthesizing the agronomic superiority of these crops with the sociological insights of agricultural extension, we present a roadmap for mainstreaming India's forgotten superfoods.*

### Introduction: The Green Revolution's Unintended Shadow

The Green Revolution was an undisputed triumph of caloric security, ensuring that India produced enough wheat and rice to feed its millions. However, as we move through the 21st century, we face a second-generation challenge: the homogeneity of our diet. While our granaries are full, our nutritional security is compromised.

According to the FAO, of the 30,000 edible plant species known to humanity, only about 30 provide 95% of the world's food energy (FAO, 2024). This dietary simplification has led to the marginalization of thousands of Neglected and Underutilized Vegetable Species (NUVS). These are crops that have sustained civilizations for millennia, providing food, fiber, fodder, and medicine, but have been ignored by formal research, extension services, and policy frameworks.

### 2. Defining the Scope: What are NUVS?

- **Neglected:** Crops that are grown primarily by traditional farmers in their ecosystems (e.g., *Bathua* or *Chenopodium*). They are "neglected" because they lack formal seed supply systems and research attention.
- **Underutilized:** Crops with documented potential for broader economic value but are currently

limited by geography, lack of processing technology, or social stigma (e.g., *Winged Bean*).

In the context of the Indian subcontinent, these include wild leafy vegetables, roots, tubers, and specific legumes that are often harvested from the wild or maintained in small, informal kitchen gardens.

### 3. The Vegetable Science Perspective: Nutritional & Agronomic Superiority

From a botanical standpoint, the "weeds" of today are often the "superfoods" of tomorrow. Breeding programs for commercial crops like tomato and cauliflower have historically focused on yield, shelf-life, and visual uniformity, often effectively breeding out nutrient density. In contrast, wild vegetables retain their phytochemical richness.

#### 3.1 The Nutrient Gap: A Comparative Analysis

Biochemical analysis reveals that NUVS are superior sources of critical micronutrients, particularly Iron, Calcium, and Vitamin A (Kumar and Singh, 2024).

Nutrient	Spinach (Commercial)	Stinging Needle (Indigenous)	<i>Chenopodium</i> (Bathua)	<i>Moringa</i> Leaves
Protein (g)	2.0	6.5	4.2	6.7
Iron (mg)	2.7	10.0	4.0	7.0
Calcium (mg)	73	481	150	440
Vitamin C (mg)	28	25	35	220
Fiber (g)	2.2	4.0	3.8	0.9
Beta Carotene (µg)	2800	5000+	1700	6700

[Data Source: Compilation of ICAR & NIN Nutrient Databases]

**Table 1: Nutritional Comparison of Commercial vs. Indigenous Vegetables (Per 100g)**

As shown in **Table 1**, species like Stinging Nettle (*Bichu Booti*) and *Moringa* provide vastly superior micronutrient profiles. For rural populations suffering from anaemia, these are not just vegetables; they are affordable nutraceuticals.

#### 3.2 Climate Resilience: The Genetic Insurance Policy

Climate change is the greatest threat to modern horticulture. Rising temperatures and erratic rainfall devastate sensitive exotic crops like Broccoli and Capsicum. However, NUVS are inherently Climate-Smart:

- **C4 Photosynthesis:** Crops like *Amaranthus* possess the C4 pathway, allowing them to photosynthesize efficiently even in high heat and drought conditions where C3 crops (like rice or wheat) fail.

- **Hardiness:** Wild relatives of brinjal and okra found in forests carry genes for resistance against the Shoot and Fruit Borer and bacterial wilt. These genes are invaluable for modern breeding programs.
- **Low Input Requirement:** Most NUVS require little to no fertilizer or pesticide, making them ideal for organic and regenerative agriculture.

#### 4. Profiles of Promising Candidates

The following are the three crops with immense potential in the Indian landscape, particularly in the Himalayan regions (Bhatia and Sharma, 2023).

##### A. Fiddlehead Fern (*Diplazium esculentum*) - The Himalayan Delicacy

Locally known as *Lingdu* or *Kasrod* in Himachal Pradesh and Northern India.

- **Botany:** It belongs to the *Athyriaceae* family. It is a non-cultivated fern that grows along water streams and damp forests.
- **Utilization:** The young, coiled fronds are harvested before they unfurl. They are rich in Omega-3 fatty acids and antioxidants.
- **Market Potential:** Currently sold in local markets at premium prices during the monsoon, but supply is erratic due to lack of domestication.

##### B. Winged Bean (*Psophocarpus tetragonolobus*) - The "Supermarket on a Stalk"

- **Botany:** A tropical legume where almost every part is edible.
- **Utilization:** The tender pods are eaten as vegetables; the leaves like spinach; the flowers in salads; and the tuberous roots are richer in protein (20%) than potatoes.
- **Market Potential:** An excellent candidate to replace soybean in protein-deficient regions.

##### C. Spine Gourd (*Momordica dioica*) - The Kartoli

- **Botany:** A dioecious cucurbit native to the Indian subcontinent.
- **Utilization:** Unlike the bitter gourd, it is not bitter. It is highly valued for its high protein content among gourds and its medicinal property of regulating blood sugar (anti-diabetic).

## 5. Socio-Economic Dimensions

While the biological potential is clear, the failure of these crops to take off is a sociological issue. Extension science provides the frameworks to diagnose these barriers and design adoption strategies (Mishra and Ray, 2025).

### 5.1 Constraints Analysis: The SWOT Grid

Strengths	Weaknesses
<ol style="list-style-type: none"> <li>1. High nutritional density</li> <li>2. Zero input cost (often wild harvested)</li> <li>3. Cultural acceptance in tribal belts</li> <li>4. High tolerance to biotic/abiotic stress</li> </ol>	<ol style="list-style-type: none"> <li>1. Lack of quality seed material (Germplasm).</li> <li>2. Poor shelf life (rapid wilting)</li> <li>3. Presence of anti-nutritional factors (e.g., oxalates) requiring specific cooking knowledge</li> <li>4. Erratic supply chain</li> </ol>
Opportunities	Threats
<ol style="list-style-type: none"> <li>1. Growing urban demand for 'Organic' &amp; "Exotic" foods.</li> <li>2. Potential for Geographical Indication (GI) tagging.</li> <li>3. Value addition (pickles, powders).</li> <li>4. Integration into Mid-Day Meal schemes.</li> </ol>	<ol style="list-style-type: none"> <li>1. Habitat loss due to urbanization and deforestation.</li> <li>2. Erosion of Indigenous Technical Knowledge (ITK).</li> <li>3. 'Weed' perception by younger generations.</li> </ol>

**Table 2: SWOT Analysis of Promoting NUVS in Indian Markets**

### 5.2 The "Stigma of Poverty"

A major psychological barrier observed in field extension work is the association of these foods with poverty. In many villages, serving Bathua or Nettle to a guest is considered disrespectful, whereas serving Paneer or Cauliflower is a sign of prosperity.

*Extension Strategy:* We need a "**re-branding**" campaign. Just as Millet was rebranded as "Shree Anna" (divine grain), NUVS need to be positioned as "*Himalayan Superfoods*" or "*Heritage Greens*" to appeal to the aspirational rural and urban youth.

### 5.3 Gender and Biodiversity

Women are the primary custodians of NUVS. In traditional agrarian structures, men manage the cash crops (wheat/apple), while women manage the kitchen gardens where these diverse species thrive.

Extension programs must specifically target women Self-Help Groups (SHGs). Empowering women with the technology to process and sell these vegetables ensures the knowledge is passed

down and the income goes directly to household nutrition (Singh and Thakur, 2022).

## 6. The Road Ahead: A Collaborative Strategic Framework

A multi-stakeholder strategy involving research, extension, and policy can be employed to mainstream these crops (Mishra and Ray, 2025).

### 6.1 Research & Breeding Interventions

- **Domestication:** Vegetable scientists must select superior genotypes from the wild. We need varieties of *Lingdu* that can be grown in fields rather than just foraged, and *Spine Gourd* varieties with higher fruit set.
- **Seed Technology:** Developing standardized seed production protocols is critical so farmers don't have to rely on wild foraging.

### 6.2 Extension & Marketing Interventions

- **Recipe Standardization:** KVKs (Krishi Vigyan Kendras) should document traditional recipes and modify them for modern palates (e.g., *Moringa Soup* or *Amaranth Granola Bars*).
- **Value Addition:** Since leafy vegetables wilt fast, simple technologies like *Solar Drying* and *Zero Energy Cool Chambers (ZECC)* must be introduced at the village level to extend shelf life.
- **Market Linkage:** Organizing farmers into *FPOs* (Farmer Producer Organizations) to aggregate produce. Connecting tribal farmers directly to urban organic stores helps bypass the middleman and secures a premium price.

### 6.3 Policy Interventions

**Public Procurement:** If the government mandates the inclusion of one local vegetable in the ICDS (Anganwadi) and Mid-Day Meal schemes per week, it would instantly create a massive, stable market demand.

## 7. Conclusion

The path to sustainable agriculture is not always about inventing something new; sometimes, it is about remembering what we have forgotten. Neglected and Underutilized Vegetable Species offer a robust solution to the triple burden of malnutrition, climate change, and rural poverty. By working together, we can turn these "weeds" into the "wealth" of the future.

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## Impact of Mechanization on Farm Productivity and Rural Labor Markets

Amit Kumar\* and Nikhil Nikas

Research Scholar, Department of Agricultural Economics, School of Agricultural Sciences,  
Nagaland University, Nagaland, India.

\*Corresponding Author Mail ID: - [amitchoudhary9950345694@gmail.com](mailto:amitchoudhary9950345694@gmail.com)

**Article ID: 12005**

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### 1. Introduction

Agricultural mechanization has been one of the most transformative developments in global agriculture over the past century. It refers to the adoption of tools, machinery, equipment, and powered technologies to improve farm operations such as land preparation, irrigation, planting, harvesting, and processing. Mechanization plays a crucial role in improving agricultural productivity, reducing drudgery, and addressing labor shortages, especially in rapidly growing economies (FAO, 2016). However, its impact is multidimensional: while mechanization enhances efficiency and yields outcomes, it also reshapes rural labor markets, sometimes creating labor displacement or altering employment patterns. Understanding these dual effects is essential for policymakers, researchers, and development agencies.

### 2. Mechanization and Farm Productivity

#### 2.1 Increased Operational Efficiency

Mechanization reduces the time and energy required for key farming operations. Equipment such as tractors, seed drills, combine harvesters, and irrigation pumps significantly accelerates farm activities, allowing farmers to expand cultivated areas and complete tasks within optimal agronomic windows (Pingali, 2007). Timeliness is particularly important for crops like rice and wheat, where delays can reduce yields significantly.

For instance, studies in India and Bangladesh found that mechanized land preparation improved crop yields by 10–20% by enabling early sowing and uniform seedbeds (Biggs *et al.*, 2011). Similarly, combine harvesters reduce harvest losses by up to 30% compared to manual harvesting (Chakraborty *et al.*, 2018).

#### 2.2 Improved Input Use Efficiency

Mechanization enhances precision in applying seeds, fertilizers, pesticides, and water. Precision seeders ensure uniform spacing, improving germination and nutrient uptake. Mechanized irrigation technologies, such as pump sets and sprinkler systems, improve water-use efficiency, which is

increasingly critical under climate variability.

Mechanization also contributes to better soil health. Conservation agriculture equipment (ridge seeders, zero-till drills) enables minimum tillage, which can reduce soil degradation and conserve moisture (Erenstein *et al.*, 2012).

### 2.3 Scaling Farm Operations

Mechanization allows farmers to manage larger landholdings with fewer labor inputs. This is particularly important in regions transitioning from subsistence to commercial farming. In sub-Saharan Africa, the use of tractors has been linked to expanding cultivated land and increasing crop output per household (Diao *et al.*, 2014).

However, the scale benefits are often captured more by medium and large farmers, raising concerns about mechanization-induced inequality.

## 3. Mechanization and Rural Labor Markets

### 3.1 Labor Displacement or Labor Reallocation?

Mechanization can reduce the demand for manual labor in operations such as plowing, weeding, and harvesting. This may lead to temporary or structural labor displacement, particularly in areas with abundant labor. For example, the adoption of combine harvesters in Punjab, India led to a sharp reduction in the demand for migrant harvest workers (Singh & Kingra, 2011).

However, numerous studies indicate that mechanization often leads to labor reallocation rather than net unemployment. Displaced workers frequently shift to non-farm rural jobs, service sectors, agro-processing, or migration to urban areas (Reardon *et al.*, 2019). Mechanization can thus accelerate rural economic diversification.

### 3.2 Wage Effects

Mechanization often leads to rising wages by reducing the supply of labor-intensive farm jobs and improving overall productivity. Higher agricultural output increases rural incomes, creating multiplier effects that strengthen rural labor markets. In China, increased mechanization was associated with a 20–30% rise in rural wages during the 2000s (Zhang *et al.*, 2017).

**However, wage effects differ by region:**

- ❖ Labor-scarce regions → Mechanization reduces costs and stabilizes production.
- ❖ Labor-surplus regions → Mechanization can depress wages temporarily or increase underemployment.

Thus, the context determines whether mechanization complements or substitutes labor.

### 3.3 Encouragement of New Forms of Rural Employment

Mechanization creates new employment opportunities in:

- ❖ machinery manufacturing
- ❖ machinery rental services
- ❖ repair and maintenance businesses
- ❖ custom hiring centers

The rise of tractor and combine harvester hiring services in India, Africa, and Southeast Asia demonstrates how mechanization can create entrepreneurial opportunities for rural youth (Baudron *et al.*, 2019).

### 3.4 Migration and Gender Impacts

Mechanization often encourages rural-to-urban migration as men seek non-farm employment. In such contexts, women may assume more responsibilities in agriculture, although heavy machinery often remains male-dominated (Lastarria-Cornhiel, 2008). Light mechanization tools (mini-tillers, reapers) can significantly reduce women's physical burden and time spent on farm tasks.

## 4. Constraints and Challenges to Mechanization

### 4.1 High Costs and Unequal Access

Mechanization requires significant capital investments. Small farmers often struggle to purchase machinery, leading to unequal access. Custom hiring centers have emerged as a key solution, but remain unevenly distributed.

### 4.2 Land Fragmentation

In South Asia and parts of Africa, highly fragmented holdings limit machinery use due to small plot sizes and irregular layouts. Mini and micro-machinery innovations are helping overcome this challenge (Paudel *et al.*, 2019).

### 4.3 Environmental Implications

Excessive mechanization—especially heavy tillage—can result in soil compaction, reduced biodiversity, and greenhouse gas emissions. Sustainable mechanization strategies emphasize minimum tillage, energy-efficient engines, and renewable-powered equipment (FAO, 2016).

## 5. Policy Recommendations

1. Promote custom hiring centers to ensure equitable access for smallholders.
2. Encourage lightweight and small-scale machinery suited for fragmented farms.
3. Support training programs for rural youth in machinery operation and maintenance.
4. Offer subsidies or low-interest loans for sustainable mechanization technologies.
5. Strengthen research on women-friendly farm tools to enhance gender inclusion.
6. Encourage digital platforms for machinery rental, maintenance, and smart agriculture.

## 6. Conclusion

Mechanization has a profound impact on agricultural productivity and rural labor markets. It contributes to increased operational efficiency, higher yields, and improved input use efficiency. However, its effects on labor markets are nuanced: while mechanization may reduce demand for manual labor in certain tasks, it also creates new employment opportunities and drives rural economic transformation. The overall outcome depends on regional labor availability, farm structure, and policy frameworks.

A balanced approach focused on *sustainable, inclusive, and context-specific mechanization* is essential to maximize productivity gains while ensuring equitable growth in rural communities. Mechanization should complement human labor, not replace it, and serve as a catalyst for rural development and economic modernization.

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## Price Volatility in Agricultural Commodity Markets: Causes and Policy Options

Nikhil Nikas\*, Amit Kumar

Research Scholar, Department of Agricultural Economics, School of Agricultural Sciences,  
Nagaland University, Nagaland, India.

\*Corresponding Author Mail ID: [nikhilnikas15@gmail.com](mailto:nikhilnikas15@gmail.com)

**Article ID: 12006**

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### 1. Introduction

Agricultural commodity markets are characterized by frequent and often severe price fluctuations. These swings affect farmers, consumers, traders, and policymakers, creating uncertainty in production decisions, income stability, food security, and national economic planning. Price volatility refers to the degree of variation in commodity prices over time, influenced by supply and demand side shocks, market imperfections, and external global forces (FAO, 2011). While some level of price movement is natural, excessive volatility can be harmful, particularly in developing economies where agriculture forms the economic backbone.

### 2. Causes of Price Volatility in Agricultural Commodity Markets

#### 2.1 Weather Variability and Climate Change

Agricultural production is highly dependent on weather conditions. Droughts, floods, cyclones, and unexpected temperature changes significantly reduce yields, creating sudden drops in supply that push prices up (Wheeler and Von Braun, 2013). Climate change has intensified both the frequency and severity of these events. For example, the 2010 Russian heatwave reduced wheat production by 30%, causing global wheat prices to spike by nearly 50% (FAO, 2011).

Extreme weather affects not only output levels but also global supply chains, amplifying market uncertainty and price fluctuations.

#### 2.2 Supply Chain Disruptions

Transportation, storage, processing, and distribution challenges play a major role in price volatility. Poor transport infrastructure, post-harvest losses, and labor shortages can restrict commodity movement and create artificial scarcity. During the COVID-19 pandemic, mobility restrictions and port disruptions caused volatility in global markets for maize, soybeans, and dairy products (Laborde *et al.*, 2021).

### **2.3 Global Trade Policies and Market Integration**

Agricultural markets are increasingly interconnected through global trade. Export bans, import tariffs, and quotas can significantly affect international supply and prices. For example, India's export restrictions on onions and rice often create price instability in South Asian markets (World Bank, 2020).

### **2.4 Speculation and Financialization of Commodity Markets**

Financial investors, hedge funds, index traders, and banks play an increasing role in commodity futures markets. While futures markets are essential for risk management, excessive speculative activity can lead to price bubbles or exaggerate price fluctuations (Irwin and Sanders, 2012).

During the 2007–2008 global food crisis, speculative investments were found to contribute to rapid increases in wheat, maize, and rice prices, worsening food insecurity (von Braun & Torero, 2009).

### **2.5 Input Price Shocks**

Agricultural production depends on inputs such as fertilizers, fuel, seeds, and machinery. When input prices increase sharply, production costs rise, causing farmers to reduce cultivation or switch crops, which eventually destabilizes commodity prices. The 2021–2022 spike in global fertilizer prices, driven by supply chain disruptions and geopolitical tensions, led to reduced use of fertilizers, affecting global crop productivity (IFPRI, 2022).

### **2.6 Biological Factors: Pests and Diseases**

Outbreaks of pests (e.g., fall armyworm) or livestock diseases (e.g., avian influenza) can cause significant production losses, leading to price spikes (Day *et al.*, 2017). These disruptions tend to have immediate local effects but can spread globally due to integrated supply chains.

## **3. Consequences of Price Volatility**

### **3.1 Impact on Farmers**

For farmers, volatility creates uncertainty in planning and investment decisions. Price crashes reduce profitability and discourage long-term investments. Smallholders, who lack storage and bargaining power, are disproportionately affected (Barrett and Bellemare, 2011).

### **3.2 Impact on Consumers**

Consumers, especially poor households, face food insecurity when staple crop prices rise. Food accounts for 50–70% of household expenditure in low-income countries, so price spikes force

reductions in dietary quality and quantity (Headey and Fan, 2010).

### **3.3 Impact on National Economies**

Volatility affects government budgets through higher food subsidies, import bills, and emergency relief requirements. It also impacts inflation, monetary stability, and political stability, as seen during the 2007–2008 food riots in more than 30 countries (World Bank, 2010).

## **4. Policy Options to Manage Price Volatility**

### **4.1 Market-Based Instruments**

#### **4.1.1 Futures and Options Markets**

Futures contracts allow farmers and traders to hedge against price risk by locking in future prices. Countries with well-developed commodity markets, such as the U.S., Brazil, and China, use these instruments extensively. However, small farmers often lack access or knowledge to participate in such markets (Irwin and Sanders, 2012).

#### **4.1.2 Warehouse Receipt Systems**

Storing produce during harvest when prices are low and selling later helps smooth price fluctuations. Warehouse receipt systems allow farmers to store commodities in certified warehouses and use receipts as collateral for loans, reducing distress sales (FAO, 2018).

### **4.2 Trade and Market Policies**

#### **4.2.1 Avoiding Ad Hoc Export Restrictions**

Stable trade policies enhance market predictability. Export bans may temporarily stabilize domestic prices but increase volatility in global markets (World Bank, 2020). Long-term strategies include maintaining moderate and predictable tariff structures.

#### **4.2.2 Import Stabilization Policies**

Countries may reduce tariffs on essential commodities during global price spikes. While effective in the short term, such measures must be carefully managed to avoid long-term market distortions.

### **4.3 Public Buffer Stocks and Food Reserves**

Public food reserves, such as the Food Corporation of India's buffer stocks, help stabilize prices by releasing stocks during shortages and procuring during surpluses. However, maintaining large reserves is costly, and inefficient management can lead to wastage (Gouel, 2013).

#### **4.4 Promoting Resilient Agricultural Systems**

##### **4.4.1 Climate Smart Agriculture**

Adopting drought-tolerant varieties, precision irrigation, and conservation agriculture reduces yield variability and stabilizes production (Wheeler & von Braun, 2013).

##### **4.4.2 Diversification**

Crop diversification, livestock integration, and off-farm income sources help farmers spread risk and withstand price shocks.

#### **4.5 Social Protection Measures**

##### **4.5.1 Targeted Cash Transfers**

Cash transfers protect vulnerable households during price spikes. Conditional or unconditional transfer programs in Africa and Asia have demonstrated effectiveness in stabilizing consumption (HLPE, 2020).

##### **4.5.2 School Feeding and Nutrition Programs**

Maintaining access to food for children and vulnerable groups reduces the nutritional consequences of price volatility.

#### **4.6 Improved Market Information Systems**

Real-time information on prices, weather, and demand helps farmers make informed decisions. Mobile-based platforms in Kenya, India, and Bangladesh have reduced information asymmetry and improved bargaining power (Aker, 2011).

### **5. Conclusion**

Price volatility in agricultural commodity markets remains a persistent challenge with significant implications for farmers, consumers, and national economies. Its causes, ranging from climate change and supply chain disruptions to trade policies and speculative activities, are complex and increasingly global in nature. While volatility cannot be eliminated, effective policy interventions can reduce its frequency, magnitude, and impact.

A combination of market-based tools, sound trade policies, public food reserves, social protection, and climate-resilient agriculture provides the most robust approach. Strengthening market infrastructure, improving information access, and enhancing risk management capacity, particularly for smallholders, are essential steps toward building stable and resilient agricultural markets.

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## How Climate Change is Altering Insect Pest Behavior in Indian Farms

Kamal Yadav\*, Tejpal Yadav, Landge Amol Dadasaheb, Ajay Kumar Yadav

Research Scholar, Department of Entomology, School of Agricultural Sciences (SAS), Nagaland University, Nagaland, India.

\*Corresponding Author Mail ID: [kamalyadav9292@gmail.com](mailto:kamalyadav9292@gmail.com)

**Article ID: 12007**

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### Abstract

Climate change is transforming pest dynamics in India. Higher temperatures, altered rainfall, elevated CO<sub>2</sub>, and extreme weather are shifting insect physiology, life cycles, ranges, and interactions with crops and natural enemies. These shifts heighten outbreak risks, support invasive pests like fall armyworm, and complicate management for farmers. This article outlines the mechanisms driving these changes, presents India-focused cases (fall armyworm, desert locusts, stem borers, whiteflies), summarizes current and projected impacts on cropping systems, and highlights adaptation options including better surveillance, forecasting, climate-smart IPM, biological control, resilient cultivars, and supportive policies, with key references for further reading.

### Introduction

Climate change is emerging as a major challenge for agriculture, especially in India, where most people depend on farming. Farmers are increasingly noticing unusual pest outbreaks, shifted infestation timings, and new invasive species. These changes closely relate to rising temperatures, erratic rainfall, and frequent extreme weather events (Skendžić *et al.*, 2021). Insects are cold-blooded, so temperature directly affects their growth and activity. Even slight warming accelerates development (Skendžić *et al.*, 2021), increases feeding, and shortens life cycles, causing pests that once appeared once or twice a season to occur more frequently or during vulnerable crop stages. Pests like whiteflies, thrips, stem borers, and armyworms already show such shifts. Rainfall changes also influence pest behaviour. Long dry spells followed by sudden rains favour migratory pests such as desert locusts (Liu *et al.*, 2024), while drought-stressed crops become more vulnerable to sap feeders. These disruptions also disturb the balance between pests and their natural enemies, allowing pest populations to rise rapidly. Invasive pests are another concern. Fall armyworm, which entered India in 2018, spread quickly due to favourable climate and host availability (FAO, 2018). With warming temperatures, more invasive insects may survive in previously unsuitable regions. Climate change also complicates pest management. Traditional knowledge about normal pest timings is becoming

unreliable, leading to early or prolonged pest activity. This often results in excessive pesticide use, higher production costs, resistance development, and harm to the environment and beneficial insects. Biological control agents such as ladybirds, lacewings, parasitoids, and entomopathogenic fungi are also affected. Their activity may no longer align with pest outbreaks, reducing their natural control and allowing pests to multiply unchecked.

### **Mechanisms: how climate drivers change pest behaviour**

#### **1. Temperature — acceleration of life cycles and range shifts**

Insects are ectotherms, so their metabolism and development depend on temperature. Warmer conditions speed development from egg to adult, increasing the number of generations and raising outbreak risks, though extreme heat can reduce survival. Higher minimum temperatures also help pests overwinter in areas that were once too cold, leading to poleward and upward range expansion.

#### **2. Precipitation and soil moisture — creating boom conditions**

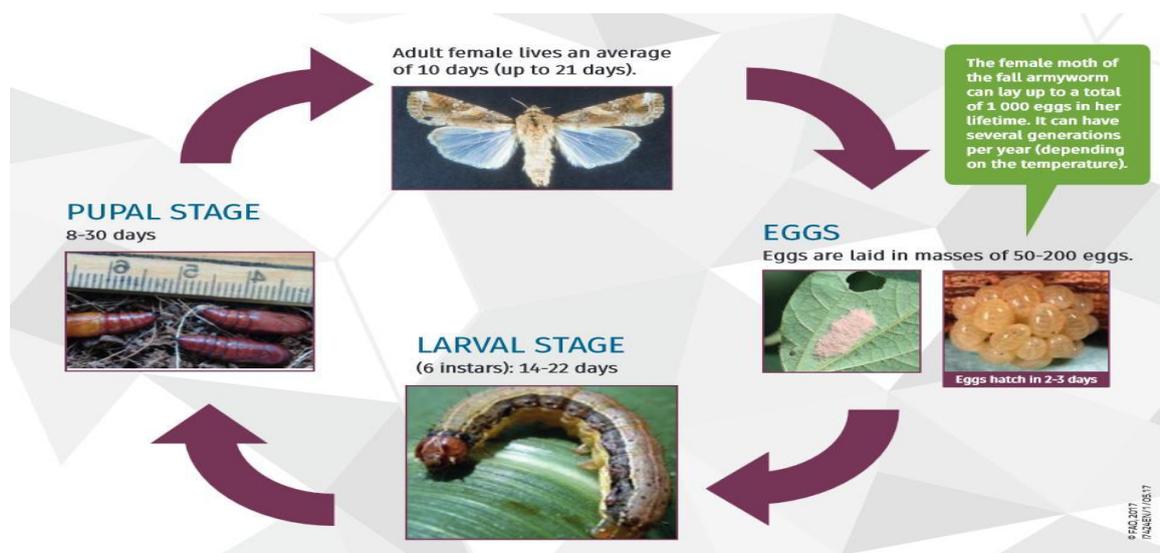
Changing rainfall patterns, with heavier rains and longer dry spells, alter pest habitats and food sources. Sudden rains that green up vegetation can trigger large outbreaks of migratory pests like desert locusts (Liu *et al.*, 2024). In contrast, drought-stressed crops become more vulnerable to certain insects or may favor pests adapted to dry conditions.

#### **3. CO<sub>2</sub> enrichment — subtle effects via crop physiology**

Elevated atmospheric CO<sub>2</sub> often increases plant growth but changes tissue quality (e.g., lower nitrogen concentration). Many chewing pests respond by eating more or altering feeding patterns; some phloem feeders (aphids, whiteflies) respond differently because sap composition changes. These indirect effects can alter pest performance and crop damage in non-intuitive ways.

#### **4. Extreme weather events and wind patterns aiding dispersal**

Stronger storms and shifts in wind regimes can carry adult insects long distances. Migratory pests such as desert locusts and certain moths can thus invade new areas. Extreme events (storms, unseasonal rains, heatwaves) can also synchronise pest outbreaks across regions, complicating localized control.



**Figure 1: Lifecycle diagram: how temperature shortens development time**

## Indian case studies — pests to watch

### A. Fall armyworm (*Spodoptera frugiperda*): a recent invader with high adaptability

Detected in India in 2018, fall armyworm (FAW) quickly spread through maize regions and later to sorghum, millets, and some vegetables (FAO, 2018). Its high reproduction, broad host range, and strong dispersal make it highly responsive to climate and cropping patterns. Warmer conditions increase its generations and extend its activity, while continuous cropping provides year-round hosts. Management has required integrated measures such as monitoring, pheromone traps, biocontrols like *Trichogramma*, and careful insecticide use.

### B. Desert locusts (*Schistocerca gregaria*): extreme outbreaks and climate links

Recent desert locust swarms in South Asia, including India's northwest, illustrate climate-driven migratory pest crises. Research links increasing erratic heavy rains and shifting wind patterns to unusual locust breeding and large swarm movements. Extreme weather and altered winds raise the risk of synchronized, cross-border outbreaks. For India, such swarms can inflict rapid, severe damage on rabi and kharif crops across vast areas.

### C. Rice stem borers, sugarcane borers, and stemborers of millets

Stem borers (e.g., *Chilo* spp., *Scirpophaga incertulas*) have temperature-dependent development. Warmer nights and higher mean temperatures can shorten larval periods, leading to more frequent generations and intensified damage in paddy, maize and sorghum. Modelling efforts

show potential shifts in outbreak timing and possible range expansions at higher elevations.

### **How climate change complicates pest management**

1. **More uncertainty and sudden outbreaks.** Traditional calendars for scouting and spraying become less reliable as phenology shifts.
2. **Greater reliance on reactive chemical control.** Farmers often respond to sudden infestations with emergency sprays, raising costs and resistance risks.
3. **Biocontrol challenges.** Natural enemies may not track pest phenology, reducing the effectiveness of classical biological control (Skendžić *et al.*, 2021).
4. **Invasives become a bigger threat.** Changing climate makes it easier for species from other continents to find suitable niches in India (FAW is an example).

### **Adaptation strategies — what can be done**

#### **1. Strengthen surveillance and early-warning systems**

- ❖ Expand meteorological-station-linked pest surveillance (automated weather stations + pheromone/ light traps) so risk windows are detected early.
- ❖ Use regional forecasting models, combining climate projections with species biology (degree-day models, species distribution models).

#### **2. Climate-smart Integrated Pest Management (IPM)**

- ❖ Promote cropping practices that reduce pest build-up: crop rotation, intercropping (push–pull), habitat management for natural enemies.
- ❖ Emphasize biopesticides and targeted use of selective insecticides only when thresholds are breached.

#### **3. Deploy biological control and habitat management**

- ❖ Strengthen use of parasitoids and predators (mass-releases, conservation biocontrol).
- ❖ Protect refuges for natural enemies and avoid broad-spectrum insecticides.

#### **4. Resistant varieties and agronomic measures**

- ❖ Breed for pest-resistant and climate-resilient crop varieties (drought-tolerant, heat-tolerant) to reduce vulnerability.
- ❖ Adjust planting dates, when possible, to avoid peak pest windows (phenology matching).

## 5. Policy, insurance and farmer support

- ❖ Invest in public early-warning systems, subsidised advisory services (KVKs, mobile apps), and insurance schemes that account for pest-related crop failures.
- ❖ Promote regional cooperation for migratory pests (locust control requires transboundary coordination).

## Conclusion

Climate change is not a distant threat; its fingerprints are already visible on pest behaviour in India. While some outcomes are complex and species-specific, the general trend points to increased unpredictability and higher outbreak risk for many pests. The response must be equally multifaceted: better surveillance and forecasting, stronger IPM and biological-control programs, farmer education, climate-informed breeding, and policy support for rapid, regionally coordinated action. Investing now in climate-smart pest management will pay dividends in saved yield, reduced pesticide dependence, and resilient livelihoods.

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## **Rise of Biological Control: Why Farmers Are Turning Toward Natural Enemies**

**Tejpal Yadav\*, Kamal Yadav, Ajay Kumar Yadav and Landge Amol Dadasaheb**

Research Scholar, Department of Entomology, School of Agricultural Sciences (SAS), Nagaland University, Nagaland, India.

\*Corresponding Author Mail ID: [tejpalyadav9887@gmail.com](mailto:tejpalyadav9887@gmail.com)

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### **Abstract**

Biological control has emerged as a key component of sustainable agriculture as farmers worldwide seek alternatives to synthetic pesticides. Growing concerns over environmental degradation, pest resistance, and market demands for residue-free produce have accelerated the adoption of natural enemies such as predators, parasitoids, and microbial agents. Advances in mass production, application technologies, and ecological research have improved the reliability and scalability of biological control across diverse cropping systems. Supported by government policies, extension programs, and increasing commercial availability, biological control offers a cost-effective and environmentally safe approach to pest management. Although challenges such as variable field performance, knowledge gaps, and supply constraints persist, biological control is becoming an essential tool for resilient, ecologically balanced crop production.

### **Introduction**

Biological control is the use of natural enemies such as predators, parasitoids, and pathogenic microorganisms to suppress agricultural pests, has become an increasingly important pillar of sustainable crop production worldwide. Over the past two decades, the rising environmental, economic, and regulatory costs associated with synthetic pesticides have encouraged farmers to adopt pest-management strategies grounded in ecological principles. Biological control forms the backbone of Integrated Pest Management (IPM), a globally promoted approach that minimises reliance on chemicals while sustaining crop yields (FAO, 2020). As awareness of biodiversity loss, pesticide resistance, and market requirements for residue-free produce intensifies, biological control is gaining momentum as a practical, effective, and long-term solution for farmers.

## **Drivers Behind the Rise of Biological Control**

### **Environmental Concerns and the Need for Sustainability**

Excessive use of synthetic pesticides has been linked to several ecological problems, including the decline of pollinators, contamination of soil and water bodies, and harm to beneficial arthropods. Bale *et al.* (2008) highlighted that chemical pesticides often disrupt natural enemy populations, which leads to secondary pest outbreaks and further increases pesticide dependency. The environmental hazards associated with chemical pest control have prompted stricter regulations globally and strengthened the push toward biological alternatives.

Biological control agents help restore ecological balance by preserving functional biodiversity. For instance, predators and parasitoids regulate pest populations naturally, reducing the need for repeated chemical interventions. According to Cock *et al.* (2016), classical biological control has been one of the most environmentally beneficial pest-management strategies, offering long-term suppression without ecological harm.

### **Economic Incentives and Market Demand**

The global rise in demand for organic and low-residue products has been a major factor driving farmer interest in biological control. Export markets, especially for fruits and vegetables, increasingly impose strict maximum residue limits (MRLs), making chemical-intensive farming risky for producers. Biological control offers a residue-free solution that aligns with consumer and regulatory expectations.

Moreover, biological agents are becoming more cost-effective due to improvements in mass production. The global biocontrol market is expanding at more than twice the growth rate of the synthetic pesticide market, driven by increased adoption by farmers and advances in commercialization (Leung *et al.*, 2020). In many cases, biological control also reduces long-term costs by preventing resistance development and minimising repeated pesticide applications.

### **Technological and Scientific Advances**

Rapid technological progress has made biological control more practical and reliable. Improved mass-rearing techniques for parasitoids such as *Trichogramma* spp., drone-based release technologies, and the use of banker-plant systems have helped ensure successful deployment at larger scales (van Lenteren *et al.*, 2018). Meanwhile, microbial biopesticides, including Bacillus-based and entomopathogenic fungal formulations, have become easier to store, transport, and apply.

Scientific research has also advanced the understanding of natural enemy ecology, allowing for better integration of biological agents within IPM systems. Conservation biological control—

managing habitats and cropping systems to support naturally occurring enemies—has gained prominence due to its compatibility with smallholder farming systems (Gurr *et al.*, 2017).

### **Examples of Successful Biological Control**

#### **Trichogramma Parasitoids in Field Crops**

The use of egg parasitoids of the genus *Trichogramma* is one of the most successful examples of augmentative biological control. In Brazil, *Trichogramma pretiosum* releases in maize increased yields by nearly 20% while reducing chemical insecticide use significantly (Figueiredo *et al.*, 2015). Similar successes are reported in China and India for rice and cotton, where parasitoid releases have become part of large-scale IPM programs.

#### **Predatory Mites and Ladybird Beetles in Horticulture**

In protected cultivation systems, predatory mites (*Phytoseiulus persimilis*, *Amblyseius swirskii*) and ladybird beetles (*Coccinellidae*) are widely used to manage spider mites, whiteflies, and aphids. According to van Lenteren (2012), commercial biological control in greenhouses is adopted in more than 50 countries and covers millions of hectares, showcasing its global applicability.

#### **Microbial Biocontrol Agents**

Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* have shown strong effectiveness against a variety of pests, including stem borers, fruit flies, and soil-borne insects. Their safety to humans and beneficial insects enhances their appeal to farmers seeking alternatives to chemical pesticides (Vega *et al.*, 2009).

### **Policy and Institutional Support**

Government agencies, international organizations, and extension systems play crucial roles in promoting biological control. The FAO and IPPC encourage countries to adopt biological strategies as part of sustainable intensification to address food security and environmental challenges (FAO, 2020). Many nations have developed regulatory pathways that streamline registration of biocontrol products and ensure quality standards.

Public–private partnerships are also growing. For example, national biocontrol programs in India and China support mass production of parasitoids and provide subsidies for biological inputs. These initiatives reduce barriers for farmers and expand access to high-quality agents.

## Challenges in Adoption

**Despite its advantages, biological control faces certain constraints:**

- 1. Field-level variability:** Effectiveness of biological agents may vary with temperature, humidity, and landscape structure (Gurr *et al.*, 2017).
- 2. Lack of awareness and training:** Many farmers require hands-on guidance to correctly release and conserve natural enemies.
- 3. Slow regulatory processes in some regions:** Registration of microbial biopesticides and importation of natural enemies can be challenging where regulatory capacity is limited.
- 4. Supply chain gaps:** Consistent and timely availability of biological agents is still a barrier in some developing regions.

## Conclusion

Biological control is becoming a cornerstone of modern sustainable agriculture as farmers confront the rising costs and environmental impacts of chemical pesticides. The shift toward natural enemies is supported by ecological benefits, economic incentives, technological progress, and strong institutional backing. While challenges remain in ensuring consistent efficacy, improving supply chains, and expanding farmer training, the trajectory is clear: biological control is no longer an alternative approach but an essential component of resilient farming systems. As markets demand safer and more sustainable produce, and as global agriculture strives to balance productivity with ecosystem health, natural enemies will play an increasingly central role in crop protection strategies worldwide.

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