ACADEMIC INN INTERNATIONAL

ISSN NO : 2523-1189

Journal of AGRICULTURAL AND RURAL RESEARCH

open access

TECHNOLOGY DISSEMINATION IN BANGLADESH'S CROP PRODUCTION: A COMPREHENSIVE REVIEW OF SYSTEMS, ADOPTION, AND IMPACT

Md. Momraz Ali[1], Md Ruhul Amin[1, *], Md. Mostafizur Rahman[1], Dr. Md. Abdus Salam[2], Md Mahedi[1]

To cite the article: *Md. Momraz Ali, Md Ruhul Amin, Md. Mostafizur Rahman, Dr. Md. Abdus Salam, Md Mahedi (2025), TECHNOLOGY DISSEMINATION IN BANGLADESH'S CROP PRODUCTION: A COMPREHENSIVE REVIEW OF SYSTEMS, ADOPTION, AND IMPACT, Journal of Agricultural and Rural Research*, 8(2): 60-79.

Link to this article:
https://aiipub.com/journals/jarr-250801-10091/

TECHNOLOGY DISSEMINATION IN BANGLADESH'S CROP PRODUCTION: A COMPREHENSIVE REVIEW OF SYSTEMS, ADOPTION, AND IMPACT

Md. Momraz Ali[1], Md Ruhul Amin[1, *], Md. Mostafizur Rahman[1], Dr. Md. Abdus Salam[2], Md Mahedi[1]

[1] Dept. of Agronomy and Agricultural Extension, University of Rajshahi, Rajshahi-6205, Bangladesh.

[2] Principal Scientific Officer, Agricultural Economics and Rural Sociology Division, Bangladesh Agricultural Research Council, Dhaka

***Corresponding author Email: ruhul@ru.ac.bd;**

ARTICLE INFO

Article Type: Research
Received: 18 June 2025.
Accepted: 30 July 2025.
Published: 07 Aug 2025.

Keywords:
Technology Dissemination, Crop Production, Adoption of Technology, Climate-Smart Technologies, Bangladesh.

ABSTRACT

Technology dissemination is crucial for densely populated Bangladesh, with its vulnerable climate, to achieve food security and safeguard livelihoods. This review integrates information on dissemination systems, adoption trends, and their effects on crop production in Bangladesh. The review is based on secondary qualitative data. It illustrates the evolving and fragmented landscape of dissemination and adoption, encompassing public extension (DAE), research institutes (BRRI, BARI), private agribusinesses, NGOs, and digital and farmer networks. There are critical and systematic gaps, such as gender inequality, where 60 percent of women farmers do not have formal extension services. There is significant regional variation in adoption, such as 70% HYV adoption in the northwest compared to <30% in coastal regions. In addition to geography, technology type (75% HYV rice adoption vs <15% for mechanized seeders), peer influence, subsidies, profitability, risk aversion, land fragmentation, digital access, and fragmentation all play key roles. Dissemination has significantly improved productivity, with rice yields tripled since the 1970s, as well as enhanced climate resilience, with over 1.2 million hectares planted with saline-tolerant rice. However, some trade-offs result in agrochemical overuse, harming water and soil, which is often caused by mechanization. This also displaces labor, excluding smallholders and women. Scalable impact is limited by systemic and fragmented extension, inconsistent policies, and infrastructure gaps. To achieve a balance between productivity, sustainability, and resilience, we recommend digitizing extension services, cultivating inclusive public-private partnerships, prioritizing climate-smart technologies tailored to specific contexts, and integrating equity into dissemination frameworks. To integrate equity into dissemination frameworks, it is essential to ensure that extension services are accessible to marginalized groups, including women and smallholder farmers, by providing targeted training and resources tailored to their needs. Developing gender-sensitive policies and programs can help address the specific needs and challenges faced by women farmers. Additionally, fostering community-led initiatives and participatory approaches can empower local stakeholders and ensure that the diverse voices of all farmers are represented and heard in decision-making processes.

1. INTRODUCTION

As one of the most agriculturally dependent and densely populated nations in the world, Bangladesh relies on crop cultivation as the cornerstone of its national survival (Jamal et al., 2023). Agriculture, which combines both crops and livestock, contributes around 11.5% of the national GDP and employs 40.6% of the workforce (Mujeri & Mujeri, 2021). Additionally, the country sustains over 170 million people on a land area equivalent to that of Illinois, thereby fueling both food and nutrition security (Oluwole et al., 2023). (Mavroeidis et al., 2022) indicates that rice, often referred to as the symbol of food sovereignty in the country, constitutes 75% of calorie intake and is grown on 78% of the cultivable land. On a macroeconomic scale, the rural economy is closely tied to the seasonality of cropping, dominated by approximately 20.5 million smallholder households with an average land size of 0.5 hectares, competing to become the most profitable smallholder farmers in a biophysically fragmented and market-volatile region. This degree of dependence is increasingly difficult in the context of multiple crises.

It has the highest population density, with more than 1,265 persons per km^2 (Islam et al., 2021). This is further worsened by the accelerated rate of soil degradation, where 41% of the topsoil is severely nutrient-depleted with little to no chance of recovery. Change in climate acts as a multiplier of an existential threat: accelerated rate of sea level rise introduces salinity to 30% of coastal cropland, erratic monsoons punch a 10-to-12-week window of opportunity for planting calendar, and increased flooding partially or completely submerges 60% of the country's land in extreme years. At the same time, major crops like rice still have productivity gaps. Rice productivity is estimated to have tripled since the 1970s. However, it is currently only at 70-80% of its potential. A combination of increasing pressures — demographic, environmental, and agronomic — means that more than just small, incremental changes are needed. The dissemination and adoption of locally relevant farming practices, therefore, serve as a vital pathway by which the conflicting demands of food and water security (Wakweya, 2023). Ecological sustainability and economic security can be reconciled in a country where the population and resources are always in a delicate balance (Flamm & Kroll, 2024).

In this review, agricultural technology diffusion is envisioned not as a one-directional provision of tools, but rather as a social-technical process of co-producing solutions to multi-scalar demands in diversified farming systems.

The integration encompasses the entire ecosystem of knowledge, artefacts, practices, and information flows (from generators to extension services, NGOs, digital platforms, and even input dealers) to end-users, in this case, farmers and cooperatives, along with the evolving loops that sustain the refinement of these processes (Gerster et al., 2024). The domains span five areas: a) Concerning the domain of mechanization, small technologies like power tillers and reapers, along with precision equipment such as laser land levelers and seed drills, aim at addressing the challenge of labor scarcity and improving productivity; b) Genetic and biological innovations are also targeting the enhancement of productivity, which include high-yielding and stress-tolerant seed varieties such as *BRRI dhan88* submergence, and *BARI gom33* for heat, along with bio-fertilizers and biocontrol agents (Shabrin Jahan Shaili et al., 2025); c) Some of the other digital agricultural solutions that are emerging include mobile advisory services, crop health remote sensing monitoring, IoT-based irrigation automation, and AI-based decision support systems; d) Concerning agrochemical advances, there are also slow-release fertilizers, micronutrient-containing fertilizers with targeted precision for specific pests, and subsector-specific pesticides that aim at improving input efficiency; e) Climate-smart management includes AWD for rice, zero tillage, and integrated pest management (IPM), and salt-affected soil reclamation. Successful dissemination, however, involves more than just the dissemination of the good; it involves intertwined investments in knowledge co-creation through farmer field schools, financial inclusion through subsidies and credit, market availability, and socio-cultural acceptance.

Implementation of the DAE and BADC policies for agribusiness involves ACI and Lal Teer as private sector actors, as well as BRAC and CARE as NGO actors, alongside farmer organizations, each of which has differing and at times opposing interests (Uddin, 2022). Fragmentation and systemic constraints coexist within the innovation and delivery of agricultural technology in Bangladesh (Kamruzzaman et al., 2023). The Green Revolution was followed by the implementation of a series of dissemination strategies, which included state-subsidized input supply, participatory extension, and current participatory digital extension. Adoption of non-rice technologies has stagnated, with a costly <15% adoption rate for mechanical seeders (Connor et al., 2021). There are stark regional disparities, such as the comparison between the northwestern saline regions and the Satkhira coastal regions, which demonstrate a striking difference in HYV adoption; 70% in the former, and <30% in the latter (Haque et al., 2025). Additionally, 60% of women farmers are excluded from formal extension services and instead rely on peer-to-peer informal networks. Despite the abundance of empirical studies conducted from a singular disciplinary approach—such as assessing the impact of specific rice varieties on yield, or pilot evaluations of SMS advisories—there is a marked lack of interdisciplinary collaboration.

However, we lack a synthesis on the effectiveness of extension systems, the acceptance or rejection of innovations by farmers, and the productive (economic, social, and environmental) outcomes in a given context. This lack of synthesis and analysis conceals systemic leverage points and slows the shift from reaction to response in the form of (project level) reaction versus (strategic) realignment. Consequently, very few framework-based policies focused on evidence have been formulated to prioritize funding, scale successful frameworks, or mitigate counterproductive situations, such as input overexploitation, which can be fueled by technology marginalization.

This comprehensive analysis thus captures the following four overarching goals:

First, conduct a systemic mapping and critical assessment of the form, actors, governance, and performance of dissemination systems active in the major agro-ecological zones (AEZs) of Bangladesh, focusing on the 'coordination failures' of institutional coordination focusing on public extension (DAE), the research actors (BRRI, BARI), the private supply chains, and the grassroots level networks. Second, we focused on the diverse economic (land tenure, gender, capital access), cognitive (risk perception, digital literacy), and institutional (subsidies, credit, market promise) drivers of uptake that collectively shape farmers' decisions. Thirdly, measuring the social equity implications (the resilience of livelihoods, the burdens of labor, and the inclusion of gender) alongside productivity gains and cost reductions deepens the understanding of the full impact of disseminated technologies and social externalities, such as environmental health, soil, water, and biodiversity. Lastly, based on this synthesis, we formulate actionable and scalable strategies to transform reconfiguration into a strategic choice for sustainable intensification, addressing critical systemic gaps ranging from R&D-extension divides to digital divides. Through the integration of these dimensions, this review aims to transcend siloed analysis, equipping decision-makers, researchers, and practitioners with a unified knowledge framework that facilitates the state's technology penetration and serves as a catalyst for Bangladesh's agrarian resilience and inclusive growth.

2. METHODOLOGY

This study employs qualitative review techniques to analyze the context, stakeholders, adoption dynamics, and impacts associated with the dissemination of agricultural technologies within the crop production sector of Bangladesh. The review is based on secondary data gathered from numerous sources, including scholarly journal articles, government publications, policy documents, institutional publications, and relevant monographs. Data were collected from scholarly databases like Scopus and Google Scholar, alongside national institutional repositories such as the Department of Agricultural Extension (DAE), Bangladesh Bureau of Statistics (BBS), Bangladesh Rice Research Institute (BRRI), Bangladesh Agricultural Research Institute (BARI), and Bangladesh Agricultural Research Council (BARC). The scope was expanded to include reports and evaluations from international agencies such as the FAO, World Bank, and USAID, to incorporate the global perspective. The selection of materials was based on topical Focus, including only those pertinent to Bangladesh, as well as the reliability of the institutions. The data were collected and analyzed thematically to determine the trends and the technologies associated with crop adoption. The specific Focus included the functions of public and private entities, the rise of digital platforms, the drivers of technology adoption, and the diverse effects on productivity, livelihoods, and sustainability. Drawing on the literature and its insights, the narrative craft within the analysis framework integrates the literature to tell a story that advances the rest of the paper.

While covering a wide array of data sources, the review is not without its drawbacks. These include the unequal distribution of empirical research within regions and technologies, as well as the inter-source methodological diversity, which limits the cross-source comparability of the findings. Despite this, the synthesis serves as a sound starting point for the deeper exploration of the intricate relationship of agricultural technology adoption in Bangladesh.

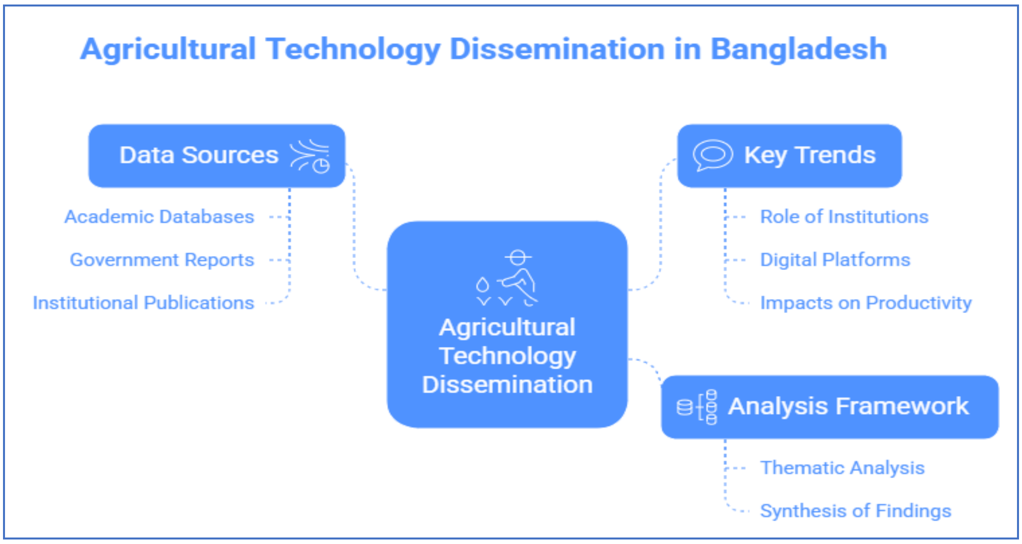

Figure 1: Methodology of Agricultural Technology Dissemination in Bangladesh.

3. TECHNOLOGY LANDSCAPE IN BANGLADESHI CROP PRODUCTION

3.1. Disseminated Key Technologies

The crop sector in Bangladesh, in particular, is witnessing an inflow of new technologies to alleviate the existing challenges of low productivity and climate change impacts. This is an innovation in the following four interrelated areas:

Flagship subs *BRRI dhan88*, which is submergence tolerant and bred for the flood-prone Haor basins. *BINA dhan23*, which is zinc-enriched and meant for nutritionally deficient soils. *BRRI dhan97*, which is also saline-tolerant, is bred for coastal zones and is a low-yielding rice variety. Beyond rice, drought-adaptive *BARI Hybrid maize15* and late-blight resistant *BARI alu87* potato have enabled the shift to high-value crops. Additionally, these crops account for approximately 85% of the cereal acreage and around 45% of the vegetable acreage.

Resource-efficient technologies address the critical shortage of inputs. DSR (Direct Seeded Rice), which is practiced on 0.3 million hectares of land, saves 60% on labor and 35% on water compared to transplanted rice (Chaudhary et al., 2023). Micro-irrigation (drip/sprinkler) is also restricted to using less than 5% of cultivated land for tea and high-value crops due to the steep capital costs of $1,200 per hectare. This is, however, useful in the high-value tomato belts of Bogra. Guided by state subsidies, laser leveling is gaining traction as a method of land development. It improves water distribution in 15% of the sugarcane cultivated land in the northwestern wheat belts by 20% and lowers diesel consumption.

Climate-smart Agriculture (CSA) practices focus on mitigation and adaptation. Currently, saline-tolerant rice varieties *BRRI dhan67* and *BINA dhan10* are cultivated on approximately 1.2 million hectares in the coastal regions of Satkhira and Khulna (Akter et al., 2023). In the Haor wetlands, short-duration maize hybrids, for example, *BARI Hybrid bhutta19*, are pre-monsoon flood-adapted. Furthermore, there are agronomic practices such as residue mulching in drought-prone Barind regions, as well as hybridized indigenous innovations, including floating gardens, in flood-affected areas (Mahedi, Shaili, et al., 2025).

3.2. Evolution of Technologies: From Green Revolution to Resilience

Technology dissemination can be categorized into three distinct eras:

a) Green Revolution (1960-1990): Government-sponsored HYV and fertilizer use initiatives centered on achieving calorie sufficiency. For rice, yields increased threefold from 1.5 tons to 4.5 tons per hectare. However, 30% of the soil experienced degradation due to the excessive use of agrochemicals.

b) Efficiency Era (2000-2010): During this period, resource optimization technologies, such as DSR and drip irrigation, emerged in response to the over-extraction of groundwater and the diminishing labor supply.

c) Climate-Resilience Shift (2015-present): This period marks the dominant practice of planting flood- and saline-resistant varieties, as well as the use of digital advisory services. This is primarily due to the USD 500 million allocated annually for adaptation financing.

Table 1: Major Crop Technologies in Bangladesh – Deployment Scale and Impact.

Technology Type	Key Examples	Primary Purpose	Scale of Deployment
HYV Rice	*BRRI dhan88, BINA dhan23*	Flood/salinity tolerance; biofortification	**Widespread** (75% rice area)
Hybrid Maize	*BARI Hybrid maize15*	Drought adaptation, high yield	**Moderate** (0.5M ha, NW region)
DSR Systems	*Drum seeders + herbicides*	Water/labor efficiency	**Expanding** (0.3M ha, central districts)
Micro-Irrigation	*Drip kits (BADC/NGO-subsidized)*	Water conservation	**Limited** (5% veg. farms)
Mobile Agri-Advisories	*Krishoker Janala (DAE), Crop Reformer (AI)*	Real-time decision support	**Rapid Growth** (2.1M users)
Saline-Tolerant Rice	*BRRI dhan67, BINA dhan10*	Coastal adaptation	**Targeted** (1.2M ha, coastal zone)
Floating Gardens	*Dhap, baira cultivation*	Flood-season production	**Niche** (20,000 Haor households)

4. DISSEMINATION SYSTEMS AND ACTORS

In Bangladesh, the efficient communication of agricultural innovations relies on a range of participants and methods that are continually evolving. This intricate system encompasses public, private, and non-governmental sectors, and increasingly utilizes both modern digital and traditional social media to connect with millions of farmers across diverse landscapes.

4.1. Public Sector Mechanisms

The dissemination of agricultural technology remains the responsibility of the Government of Bangladesh (GoB), which serves as the country's principal planner and funding agency. Their work is centered around two major divisions. The Department of Agricultural Extension (DAE) has a wide-reaching network of personnel stationed at the union level, serving as the frontline delivery system. One of the most essential farming education methods is organizing training sessions on modern crop, pest, and management practices. Additionally, field days enable farmers to observe the practical application of technologies on designated farms through direct and participatory interaction with experts. In addition, and to a more notable degree lately, the Farmer Field School (FFS) approach encourages season-long participatory action research and problem-solving, which strengthens understanding and fosters the development of complex skills among farmer groups. Apart from DAE, some national Research Institutes such as the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Agricultural Research Institute (BARI) are equally crucial as early applied research institutes (Debsharma et al., 2024).

They participate in on-farm research trials to learn about new technologies (varieties, practices) to evaluate and modify them in different agro-ecological zones, creating localized evidence of their performance and suitability. In addition, these institutes play a pivotal role in multiplying foundation and breeder seeds of publicly developed varieties. These seeds are then channelled to larger multiplication programs, which are coordinated with the Bangladesh Agricultural Development Corporation (BADC) and private seed companies for broader dissemination.

4.2. Private Sector and NGOs

The private sector and NGOs often augment and, at times, take the lead in dissemination activities due to their market-driven approach. Agribusiness firms, preeminent input suppliers, such as those for seeds, fertilizers, and pesticides, as well as machinery companies, are the primary disseminators (Hu et al., 2024). Through field demonstrations and dealer networks, they market their products to farmers. These inputs are often accompanied by technical advice, which bolsters, especially for commercially successful technologies, their overwhelming reach. Large NGOs, such as BRAC and CARE, also have a significant grassroots presence and engage with the community. They integrate the dissemination of agricultural technologies with their broader rural development programs targeting poverty, nutrition, and the empowerment of women.

Community-based training, input provision (sometimes via microfinance), and the setting up of demonstration plots serve to reach out to marginalized and smallholder farmers who are often neglected by public systems. Public-Private Partnerships (PPPs) have emerged as a crucial model to leverage the strengths of both sectors. A notable case is the partnership between ACI Seed and the GoB (often involving BADC and research institutes) in the commercialization and production of high-yielding, disease-resistant rice and vegetable seeds. These partnerships aim to expedite their availability and adoption by private marketing and distribution channels, while providing public research infrastructure and regulatory frameworks.

4.3. Digital Platforms & Media

Information and Communication Technologies (ICTs) are rapidly transforming the dissemination landscape, offering unprecedented reach and timeliness. Seasonal Radio and TV broadcast programs on agricultural issues continue to serve as the primary source of information for the rural populace. Expert interviews and market price broadcasts are also part of the programming. With the increasing penetration of mobile phones, SMS offers are becoming increasingly popular. Union Digital Centers (UDCs) and other agribusinesses, such as Krishoker Janala and ACI Agribusinesses, are directly providing farmers with temperature and pest forecasts, market information, and advisory tips on cultivation and pest management.

Extension agents, input companies, progressive farmers, and agricultural organizations actively use YouTube and Facebook to post videos, success stories, technical guides, and foster peer-to-peer dialogues with younger farmers or those who prefer learning visually.

4.4. Farmer-to-Farmer Networks

Aside from formal institutional frameworks, informal Farmer-to-Farmer (F2F) networks are crucial for information dissemination, and they are viewed as highly reliable. Often, lead farmers or progressive farmers are trained by DAE or NGOs, and they serve as local champions who broker knowledge. These farmers are incredibly influential due to their adoption of information and technology. They give informal advice and share experiences, fostering a level of trust and credibility that formal agents sometimes lack. Cooperatives and farmer groups create organized avenues for F2F interactions. They share and discuss problems, make collective purchases of inputs, and sometimes receive training or demonstration from outside agencies. These networks are essential in reinforcing messaging, localizing the context of work through collective innovation, and sustaining the adoption of findings and proven methods long after external assistance has ended.

Table 2: Strengths and Weaknesses of Dissemination Channels in Bangladesh.

Dissemination Channel	Key Strengths	Key Weaknesses
Public Extension (DAE)	Extensive nationwide network; Mandate for broad coverage; Link to research; Free/low-cost services; Government legitimacy.	Resource constraints (staff, transport, budget); Top-down approach sometimes; Limited capacity for continuous follow-up; Bureaucratic delays; Variable staff quality/motivation.
Research Institutes (BRRI, BARI)	Source of credible, tested technologies; Expertise in adaptation; Foundation seed production; On-farm validation.	Limited direct farmer reach; Focus often on technology generation over dissemination; Resource constraints for large-scale outreach.
Private Sector (Agribusiness)	Market-driven efficiency, Strong distribution networks, Resources for promotion/demos, Responsive to farmer demand, Focus on profitable technologies.	Primarily promotes own commercial products; May neglect non-profitable or public promising technologies; Risk of biased information; Limited reach to resource-poor/subsistence farmers.
NGOs (e.g., BRAC, CARE)	Strong grassroots presence & community trust; targeting marginalized groups; holistic approach (tech + finance, etc.); flexibility and innovation; often focusing on women.	Project-based funding can limit sustainability; geographic coverage may be patchy, variable technical expertise may lead to duplicated efforts, or work may be conducted in silos.
Public-Private Partnerships	Leverages strengths of both sectors; Accelerates scaling;	Complex coordination/management; Potential conflicts of interest; Sustainability depends on

(PPPs)	Combines public research with private distribution; Can improve efficiency/resource use.	continued mutual benefit; Risk of private capture of public resources.
Digital Platforms (SMS, Apps)	Rapid, broad reach; timely information (e.g., alerts); cost-effective at scale; accessible to youth; can be highly targeted.	Digital literacy and access barriers (especially for the elderly, women, and those with limited financial means); infrastructure limitations (including connectivity and power); information overload/quality control; and limited interactivity/feedback in basic systems.
Traditional Media (Radio/TV)	Extensive reach, including remote areas; low access barriers; familiar format; suitable for seasonal awareness.	One-way communication; Limited depth/detail; Generic content, less localized; Scheduling may not align with farmers' needs; Declining listenership/viewership among youth?
Farmer-to-Farmer Networks	High trust & credibility (peer validation); Social learning; Low cost; Contextual adaptation; Sustainability through social capital.	The quality and accuracy of the information shared can vary. The slow diffusion speed may reinforce existing practices over new technology. It has limited reach beyond the immediate network and is difficult to track/support systematically.

5. ADOPTION PATTERNS AND DETERMINANTS

It is essential to recognize that understanding how, where, and why agricultural technologies are adopted in Bangladesh facilitates the improvement of their dissemination and impact on crop production. The adoption pattern is a complex system of social, economic, institutional, and infrastructural factors (Curry et al., 2021). This section of the paper evaluates the different regions and crop types in terms of adoption, analyzes the primary motivators of technology adoption, and outlines the ongoing challenges that hinder broader adoption.

5.1. Adoption Levels

In Bangladesh, regional differences exist in the adoption of technology in crop production (Sarker et al., 2021). A notable example is the northwestern part of the country, specifically the districts of Rajshahi, Dinajpur, and Bogura, where the adoption rate is higher (Nazu et al., 2022). These areas tend to have favorable agro-ecological conditions and well-developed market systems, along with improved extension services. Coastal areas, such as Khulna and Barisal, have lower adoption rates due to consistent salinity intrusion, inadequate infrastructure, and natural disasters.

Another thing to note is that there are crop-specific trends with adoption. Technologies related to staple crops, especially rice, are adopted far more frequently than those targeting high-value crops and precision agriculture.

For instance, the adoption of high-yielding varieties (HYVs) of rice is nearly universal due to the yield advantages they offer. In contrast, precision farming, which utilizes GPS-guided equipment, remote sensing applications, and sensor-based irrigation, still has limited adoption outside of pilot projects and wealthy commercial farms. The adoption of integrated pest management (IPM) and the system of rice intensification (SRI) also varies based on the cognitive and socioeconomic profile of farmers, the extent of patronage of extension services, and the return on investment from farming.

5.2. Drivers of Adoption

Social, economic, and institutional factors are key drivers of technology adoption in Bangladesh, as well as in agriculture in general (Sharna et al., 2022). From a financial standpoint, higher returns and reduced operational costs act as strong drivers. The adoption of technology appears more certain when there are promises of higher yields, reduced inputs, or enhanced climate resilience. Additionally, cost-cutting measures in agriculture, such as AWD irrigation and no-till cultivation, are more welcomed when input costs are high and labor is scarce. Social factors also have an equally significant impact. The community can influence a farmer's attitude towards adopting new interventions through peer-to-peer teaching, community lessons, and trust in extension staff. In rural communities, tight social networks mean that adoption by a small number of influential farmers can trigger adoption by the rest.

How people of different ages, genders, and cultures perceive something also affects how people make decisions. Institutional factors are equally critical. The existence of government grants, the availability of informal credit, and participation in agricultural training programs significantly increase the chances of adoption. For example, farmers who are cooperative members or beneficiaries of NGO programs tend to have greater financial and technical resources, which enable them to adopt and sustain the use of modern agricultural technologies. When done well, public-private partnerships can also provide supportive climates that reduce the adoption risks.

5.3. Barriers to Adoption

Despite these supportive factors, numerous barriers still hinder the widespread adoption of agricultural technologies in the country. Socioeconomic challenges are perhaps the most severe. The small size of landholdings means that most farmers do not have sufficient land to reap the benefits of modern technologies fully (Liao et al., 2022). Augmented by poverty, this dramatically increases risk aversion. Additionally, income volatility exacerbates the situation. Moreover, there are gender differences that affect the availability of resources and the power to make decisions. For example, female farmers are often excluded from extension services and credit programs.

Another significant barrier is technical issues. Even in cases where technologies are offered, farmers often lack the skills to operate, maintain, or tailor the equipment to local conditions.

For instance, self-service kiosks at retail stores often go unused due to a lack of training and support, as they require digital literacy skills and a basic understanding of machines. In rural areas, after-sales service and repair service providers are scarce, resulting in equipment often being abandoned due to minor technical issues. Lack of infrastructure creates more problems: weak market linkages reduce motivation for intensive production, and lack of a supply chain for quality seeds, fertilizers, or spare parts decreases the consistency of technology use (Donovan et al., 2021). In many regions, inadequate cold storage, transportation, and information systems contribute to farmers' reluctance to adopt new production technologies.

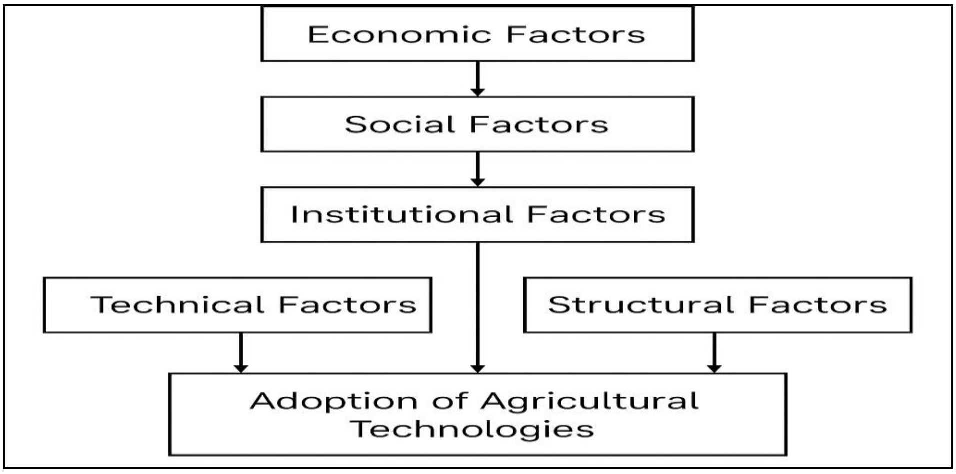

Figure 2: Conceptual Framework of Technology Adoption Determinants.

6. IMPACTS OF TECHNOLOGY DISSEMINATION

The spread and adoption of agricultural technologies in Bangladesh has profoundly and multilaterally reshaped agrarian practices. It has transformed the farm landscape, the rural economy, and the nation's environmental footprint. While the changes have driven food security and productivity, they have also presented complex socioeconomic challenges and ecological trade-offs. Thus, a balanced examination of the net effects is troubling.

6.1 Productivity and Food Security

The most noteworthy impact is on agricultural productivity, particularly in the cereal subsector. Bangladesh's near self-sufficiency in rice production, a nation once plagued by famine, is now attainable due to the widespread adoption of High-Yielding varieties of rice, along with improved irrigation and fertilizer use (Suza et al., 2024). Major cereals, such as rice and wheat, have experienced significant yield gains over the years, contributing to national food security and stabilizing food prices. Increased productivity and food security have also fostered crop diversification, especially in peri-urban and urban areas. Rural households have benefited from improved dietary diversity and increased farm incomes due to the adoption of enhanced vegetables, mangoes, bananas, spices, and high-value crops such as maize for poultry feed. Farmer returns, as well as supply, have been improved due to off-season production technologies, such as plastic tunnels and irrigation. Nevertheless, the concentration of diversification remains uneven, often limited to farmers with better access to the market, larger-scale, and more commercially oriented operators.

6.2. Socioeconomic Impacts

Changed technology has caused significant shifts, both positive and negative, within social and economic spheres: The adoption of new methods and diversification has considerably improved the income of the adopting farmers, especially those growing commercially viable crops such as vegetables, fruits, and hybrid maize. Limited but growing post-harvest economic activities are also adding further value (Layek et al., 2023).

The effects of technology on agriculture are multifaceted and vary across different contexts. The introduction of powered tillers, threshers, and reapers has considerably increased the ease and time efficiency of demanding land and harvest preparation tasks (Md Shahriar Kabir et al., 2025). Primarily, benefits women who traditionally undertook the bulk of this work. It has simultaneously given rise to new skilled service provider roles, for example, machinery operators and mechanics. It has, however, led to job losses in unskilled agricultural wage work, especially during the peak harvest season (manual reaping/hand harvesting). There is debate about the overall effects of such shifts on employment in rural areas, although shifts upstream (toward input supply) and downstream (provision of processing and marketing) are increasing.

Access disparities remain a significant issue. These access disparities often favor larger landholders, farmers with better connections (those more integrated/marketed to regional markets), and men. Women farmers often lack access to crucial resources, such as information, credit, inputs, and markets, which hinders their ability to adopt beneficial technologies, despite playing a vital role in the agricultural sector (Shahbaz et al., 2022). Landless laborers and sharecroppers face multiple challenges in adopting capital-intensive technologies, which leads to job losses. While some NGO efforts focus on the most marginalized, targeting equity gaps in access to technology and benefits is more likely to widen existing gaps.

6.3 Environmental Sustainability

Regarding the technologies that have been disseminated, their environmental impacts present a somewhat mixed view, illustrating a tension between the ambitions of productivity and sustainability.

Certain technologies advance the efficient use of resources. Water productivity in rice is enhanced by the deep placement of fertilizers, encouraging a more efficient use of water and nutrients, thereby reducing waste and the potential for pollution (Zhu et al., 2024). Conservation agriculture, characterized by minimal tillage and residue retention, although not widely adopted, has the potential for better soil health. Biopesticides and IPM adoption, though successful, reduce reliance on broad-spectrum chemical pesticides.

The drive to intensify productivity has also brought significant environmental pressures. Chemical misuse, such as the application of herbicides and nitrogen fertilizers, negatively impacts the production of high-value crops like vegetables and rice (Ali et al., 2024). This practice, driven by misinformation, short-sighted thinking, and reliance on subsidies, poses a threat to soil vitality (acidification, decline in organic matter, and micronutrient depletion), water health (nitrate and pesticide pollution), and even the survival of beneficial insects (Mahedi et al., 2025). In intensively irrigated northwestern regions, groundwater depletion is a significant concern. In addition, monoculture farming of high-yield varieties (HYVs) reduces agricultural biodiversity.

6.4 Climate Resilience

In Bangladesh, technology transfer is particularly crucial in enhancing the climate resilience of the vulnerable agricultural sector. A range of Climate-Smart Agriculture (CSA) technologies is increasingly used to manage risk: Stress-Tolerant Varieties: Maintaining production in haor floodplains and drought-prone areas (Barind Tract) and coastal zones facing sea level rise and cyclic surges needs to produce flood (e.g., *BRRI dhan51, dhan52*), drought (*BRRI dhan56, dhan66*), and saline (*BRRI dhan67, BINA dhan-10, BINA dhan-11*) tolerant rice and pulses, and vegetables. These crops, tolerant pulses, and vegetables are also emerging.

Adaptive Management Practices, such as Water Saving Technologies (WST) like Alternate Wetting and Drying (AWD), not only conserve water during the dry season but also reduce methane emissions. Raised bed farming protects crops in areas prone to flash floods.

With improved weather forecasting sent via SMS and other digital platforms, farmers can now plan their planting, irrigation, and harvesting activities well in advance, thereby avoiding weather-related challenges. Adopting diversification into climate-resilient crops, such as sunflower and sesame, as well as certain fruits, also mitigates risks. Early Warning & Information Systems: For farmers in distant locations, the digital channels providing early warnings and precautionary measures, such as those about cyclones or floods, are instrumental.

The overall effects of technology dissemination in Bangladesh have a distinct interplay of sharp advancements in productivity and food security, increased socioeconomic well-being, but also raise equity issues, and significant environmental impacts, with encouraging paths toward enhanced resource efficiency and climate resilience. In dissemination systems, continuous adaptation, targeting, and integration of sustainable approaches are necessary to maximize positive impacts while minimizing negative impacts.

7. CRITICAL CHALLENGES AND CONSTRAINTS

Bangladesh still grapples with multifaceted challenges in overcoming effective adoption pathways, especially in the crop production industry, despite advancements in agricultural technologies and a greater Focus on their dissemination. These challenges span the integration system, individual-farmer level, policy, and infrastructure. Addressing these issues is crucial to formulating context-sensitive and operationally practical strategies.

7.1 Systemic Issues

Bangladesh's agricultural extension services face systemic issues, particularly concerning the fragmented and underdeveloped nature of agrarian extension services (Biswas et al., 2021). Under the Division of Agricultural Extension (DAE), the primary institution responsible for delivering and extending agricultural information and technologies to farmers faces severe budget and staffing issues that limit its operational outreach. The limited availability of trained extension staff in marginalized and remote areas leads to inadequate outreach services for farmers. More than one institution, whether public, private, or non-governmental, is attempting to assist farmers with technology delivery, diagnosis, and treatment services; however, there is no coordination among their efforts. The result of this is that farmers and their groups are uncertain about which technology to prioritize and which to consider secondary, as there is no harmony in their actions. No standard policy or basic framework for inter-agency extension cooperation is in place, which allows for the free exchange of information and services to farmers.

7.2 Farmer-Level Challenges

Farmers face several challenges in adopting and utilizing agricultural technologies at the micro level. Many smallholder farmers in Bangladesh are risk-averse due to their reliance on traditional farming methods, uncertainty regarding new technologies, and a lack of a financial cushion to absorb potential losses (Al-Maruf et al., 2021). This challenge is made worse by economic difficulties. Along with the lack of affordable farming methods, such as improved seeds, irrigation tools, and other mechanized equipment, many farmers also require financial assistance to adopt modern methods. Although microfinance institutions and government subsidy programs do exist, they are neither reliable nor accessible to the farmers (Mahedi, Saha, et al., 2025; Nabi et al., 2018). Additionally, the gap in digital literacy presents a significant obstacle to the effective use of ICT in modern agricultural extension. Mobile, SMS, and internet training and information platforms are unavailable to a large portion of the farming demographic, particularly elderly and less educated individuals. Thus, modern information and training remain out of their reach.

7.3 Policy and Infrastructure Gaps

Policy gaps and inconsistent infrastructure impose stringent limits on initiatives aimed at leveraging the popularity of technology. Government subsidy schemes—while beneficial—are often implemented unevenly, lacking transparency and continuity, which undermines farmer trust and long-term planning. This also contributes to the widening gap that exists due to the difference between the research and extension work. Research institutions invest a significant amount of time and effort into the innovations they develop. This is helpful, but due to the lack of mechanisms to scale and localize innovations, farmers often have limited access to the results of these innovations for a very long time. The lack of connection means that many research findings are not utilized as intended or do not lead to practical applications. The gap in internet access compounds these issues. In many areas of rural Bangladesh, internet access is still very limited or non-existent, which hampers the use of digital extension tools and e-agriculture platforms. Without considerable investment in digital and human infrastructure in rural areas, the potential of technology-augmented agriculture will remain inaccessible to many farming communities.

8. FUTURE PATHWAYS AND RECOMMENDATIONS

The practical and timely dissemination of agricultural technologies has become crucial for addressing the dual challenges of climate change and food security in Bangladesh. Significant strides have been made; however, the hurdles outlined in this review suggest that there is a growing need for strategic shifts in policy, institutional structures, and research frameworks that govern these areas. The recommendations provided aim to create a paradigm that ensures improved dissemination, adoption, and sustained application of agricultural technologies in the nation's crop production systems.

8.1. Modifying the Agricultural Extension System

An immediate priority is to improve the existing gaps in agricultural extension services, which are the primary avenue for agrarian innovations to reach farmers, through modernized dissemination systems. The digitization of processes used by the Department of Agricultural Extension (DAE) constitutes one of the most impactful strategies. The use of mobile applications, SMS-based advisories, digital dashboards, and even AI-based decision-support systems can enhance access to and the precision of timely information. However, efforts to improve digital access must be coupled with training to enhance the digital literacy of farmers and extension workers.

Aside from digital efforts, there is a need to embrace public-private partnerships (PPPs) to advance the dissemination of technology.

The collaboration between government departments, private agro-tech firms, NGOs, and research institutions has the potential to foster innovative synergies and increase efficiency. In this regard, agribusiness firms can aid in the distribution of modern inputs and equipment, while NGOs can help mobilize grassroots support and community trust. In addition, technology development and dissemination must be grounded in farmers' lived experiences, so these approaches should be scaled up (Adamsone-Fiskovica & Grivins, 2022). These include farmer field schools, innovation platforms, and the co-creation of technologies with end users. These approaches improve local relevance and adoption. These models allow farmers to engage in active experimentation and participate in feedback and refinement cycles, increasing ownership and adaptability.

8.2. Enabling Environment

The lack of supportive policies, infrastructure, and inequitable access to, as well as the slow adoption of, applicable technologies fundamentally stem from these barriers. Accessible and well-structured policies, alongside targeted subsidies, should be refined to prioritize marginal and smallholder farmers who lack the monetary resources to invest in innovations. Financial aid catering to smallholders, including microfinance institutions, cooperatives, formal banks, and credit with less stringent collateral and seasonal cash flow requirements, should be expanded. Additionally, the construction and implementation of gendered agricultural programs that support women farmers, particularly through land grants, training, and financial services, is equally important.

Infrastructure aimed at enhancing rural connectivity needs immediate attention.

Investments in rural broadband, mobile networks, and Internet of Things (IoT) infrastructure are crucial to harnessing the full potential of digital extension services and precision farming. Furthermore, a consistent power supply, access to market infrastructure, and transportation networks are equally essential to ensure that the increased production resulting from the adoption of new technologies leads to improved livelihoods (Mahedi, Pervez, et al., 2025).

8.3. Research and Innovation Priorities

The development of climate-smart agriculture (CSA) technologies tailored to local contexts necessitates a national research agenda that focuses on collaborative and cross-cutting issues. These dryland-oriented technologies include, but are not limited to, drought-tolerant crop varieties, low-cost irrigation, and resource-conserving practices designed for specific agro-ecological contexts in biodiversity hotspots and vulnerable regions, such as the Barind Tract, haor wetlands, and coastal zones.

Additionally, the adoption and implementation of low-cost digital solutions, such as solar-powered sensors, mobile diagnostics, and knowledge delivery systems, warrant greater attention. These innovations must be both socially inclusive and economically sustainable.

Finally, more attention to longitudinal and impact-based research that analyzes the sustainability of technology adoption is necessary.

Although short-term adoption trends have been recorded, analyzing long-term trends may reveal insights into the perennial performance of technologies, the evolution of farmer practices, and the types of institutional support required for sustained adoption. This evidence will be vital for agile, adaptive policy-making, guiding investment streams from donors, and reforming extension services.

9. CONCLUSION

Bangladeshi crop farming distribution represents a dynamic and uneven system, characterized by spatial agricultural ecosystems, institutional silos, and varying levels of farmer sophistication. Although the country has made positive strides in expanding access to High-Yielding Varieties (HYV), climate-smart innovations, and digital advisory services, these benefits are not fully accessible to every community. Furthermore, many innovations in agriculture remain limited due to regional disparities, socio-cultural barriers, infrastructural gaps, and a lack of cooperative and collaborative approaches among the various actors involved.

As described in the review, dissemination actors, which include public institutions, private companies, NGOs, and digital intervention hubs, shape a system that influences the dissemination of technology. Economic and institutional paradigms are the core drivers, while digital access barriers, limited land, and low levels of education on the available technology are critical constraints. Environmental and climate challenges are ongoing; however, social challenges, particularly in terms of equity and environmental sustainability, persist as long-term issues.

Moving forward entails improving institutional coordination, building equitable infrastructure, broadening community-based, digitally inclusive extension services, and closing policy and financing gaps to guarantee equitable access to dissemination systems. In Bangladesh, sustainable agricultural transformation requires the reframing of technology dissemination as a multifaceted, farmer-driven process that simultaneously pursues innovation, access, equity, and resilience.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

10. REFERENCES

1. Adamsone-Fiskovica, A., & Grivins, M. (2022). Knowledge production and communication in on-farm demonstrations: Putting farmer participatory research and extension into practice. *The Journal of Agricultural Education and Extension*, *28*(4), 479–502. https://doi.org/10.1080/1389224x.2021.1953551
2. Akter, R., Hasan, N., Reza, F., Asaduzzaman, Md., Begum, K., & Shammi, M. (2023). Hydrobiology of Saline Agriculture Ecosystem: A Review of Scenario Change in South-West Region of Bangladesh. *Hydrobiology*, *2*(1), 162–180. https://doi.org/10.3390/hydrobiology2010011
3. Ali, A., Niu, G., Masabni, J., Ferrante, A., & Cocetta, G. (2024). Integrated Nutrient Management of Fruits, Vegetables, and Crops through the Use of Biostimulants, Soilless Cultivation, and Traditional and Modern Approaches—A Mini Review. *Agriculture*, *14*(8), 1330. https://doi.org/10.3390/agriculture14081330
4. Al-Maruf, A., Mira, S. A., Rida, T. N., Rahman, M. S., Sarker, P. K., & Jenkins, J. C. (2021). Piloting a Weather-Index-Based Crop Insurance System in Bangladesh: Understanding the Challenges of Financial Instruments for Tackling Climate Risks. *Sustainability*, *13*(15), 8616. https://doi.org/10.3390/su13158616

5. Biswas, B., Mallick, B., Roy, A., & Sultana, Z. (2021). Impact of agriculture extension services on technical efficiency of rural paddy farmers in southwest Bangladesh. *Environmental Challenges*, *5*, 100261. https://doi.org/10.1016/j.envc.2021.100261
6. Chaudhary, A., Venkatramanan, V., Kumar Mishra, A., & Sharma, S. (2023). Agronomic and Environmental Determinants of Direct Seeded Rice in South Asia. *Circular Economy and Sustainability*, *3*(1), 253–290. https://doi.org/10.1007/s43615-022-00173-x
7. Connor, M., Tuan, L. A., DeGuia, A. H., & Wehmeyer, H. (2021). Sustainable rice production in the Mekong River Delta: Factors influencing farmers' adoption of the integrated technology package "One Must Do, Five Reductions" (1M5R). *Outlook on Agriculture*, *50*(1), 90–104. https://doi.org/10.1177/0030727020960165
8. Curry, G. N., Nake, S., Koczberski, G., Oswald, M., Rafflegeau, S., Lummani, J., Peter, E., & Nailina, R. (2021). Disruptive innovation in agriculture: Socio-cultural factors in technology adoption in the developing world. *Journal of Rural Studies*, *88*, 422–431. https://doi.org/10.1016/j.jrurstud.2021.07.022
9. Debsharma, S. K., Akter, F., Syed, Md. A., Islam, M. R., Hasan, Md. R., Adil, Md., Sarker, Md. R. A., Karmakar, B., & Khatun, M. (2024). Dataset on developing climate-smart transplanted Aus rice variety BRRI dhan98 suitable for partially irrigated ecosystem in Bangladesh. *Data in Brief*, *57*, 111092. https://doi.org/10.1016/j.dib.2024.111092
10. Donovan, J., Rutsaert, P., Spielman, D., Shikuku, K. M., & Demont, M. (2021). Seed value chain development in the Global South: Key issues and new directions for public breeding programs. *Outlook on Agriculture*, *50*(4), 366–377. https://doi.org/10.1177/00307270211059551
11. Flamm, P., & Kroll, S. (2024). Environmental (in)security, peacebuilding and green economic recovery in the context of Russia's war against Ukraine. *Environment and Security*, *2*(1), 21–46. https://doi.org/10.1177/27538796241231332
12. Gerster, B. M., Maes, O., Rembold, F., & Callenius, C. (2024). *Agricultural Extension and Advisory Services in Low and Lower-Middle-Income Countries—Knowledge Review*. JRC Publications Repository. https://publications.jrc.ec.europa.eu/repository/handle/JRC137791
13. Haque, C. E., Shehab, M. K., & Faisal, I. M. (2025). Meeting climate change challenges in coastal Bangladesh: A study of technology-based adaptations in water use in Satkhira District. *PLOS Climate*, *4*(4), e0000460. https://doi.org/10.1371/journal.pclm.0000460
14. Hu, X., Xiao, B., & Tong, Z. (2024). Technological Integration and Obstacles in China's Agricultural Extension Systems: A Study on Disembeddedness and Adaptation. *Sustainability*, *16*(2), 859. https://doi.org/10.3390/su16020859
15. Islam, A., Sayeed, Md. A., Rahman, Md. K., Ferdous, J., Shano, S., Choudhury, S. D., & Hassan, M. M. (2021). Spatiotemporal patterns and trends of community transmission of the pandemic COVID-19 in South Asia: Bangladesh as a case study. *Biosafety and Health*, *3*(1), 39–49. https://doi.org/10.1016/j.bsheal.2020.09.006
16. Jamal, M. R., Kristiansen, P., Kabir, M. J., & Lobry De Bruyn, L. (2023). Challenges and Adaptations for Resilient Rice Production under Changing Environments in Bangladesh. *Land*, *12*(6), 1217. https://doi.org/10.3390/land12061217
17. Kamruzzaman, M., Anne Daniell, K., Chowdhury, A., & Crimp, S. (2023). Facilitating learning for innovation in a climate-stressed context: Insights from flash flood-affected rice

farming in Bangladesh. *The Journal of Agricultural Education and Extension*, *29*(4), 463–487. https://doi.org/10.1080/1389224x.2022.2082497

18. Layek, J., Das, A., Ansari, M. A., Mishra, V. K., Rangappa, K., Ravisankar, N., Patra, S., Baiswar, P., Ramesh, T., Hazarika, S., Panwar, A. S., Devi, S., Ansari, M. H., & Paramanik, B. (2023). An integrated organic farming system: Innovations for farm diversification, sustainability, and livelihood improvement of hill farmers. *Frontiers in Sustainable Food Systems*, *7*. https://doi.org/10.3389/fsufs.2023.1151113
19. Liao, W., Zeng, F., & Chanieabate, M. (2022). Mechanization of Small-Scale Agriculture in China: Lessons for Enhancing Smallholder Access to Agricultural Machinery. *Sustainability*, *14*(13), 7964. https://doi.org/10.3390/su14137964
20. Mahedi, M., Pervez, A. K. M. K., Rahman, S. M. M., Sheikh, Md. M., & Shaili, S. J. (2025). Emerging Trends in Livelihood Diversification in Rural Communities: A Bibliometric and Systematic Review. *Asian Journal of Agricultural Extension, Economics & Sociology*, *43*(4), 162–177. https://doi.org/10.9734/ajaees/2025/v43i42727
21. Mahedi, M., Saha, A., Pervez, A. K. M. K., & Shaili, S. J. (2025). Micro-credit in Bangladesh: A Comprehensive Review of its Evolution, Impact, and Challenges Using Quantitative and Qualitative Evidences. *Asian Journal of Economics, Business and Accounting*, *25*(5), 1–18. https://doi.org/10.9734/ajeba/2025/v25i51780
22. Mahedi, M., Shaili, S. J., Nurnobi, M., Sakil, A., & Shihab, A. (2025). *ADOPTION OF ORGANIC FARMING PRACTICES: A COMPREHENSIVE REVIEW OF TRENDS, DETERMINANTS, AND CHALLENGES*. *8*, 26–45.
23. Mahedi, M., Shaili, S. J., Nurnobi, M., Shihab, A., & Sakil, A. (2025). *EFFECTS OF CLIMATE CHANGE ON LIVELIHOODS IN DROUGHT-PRONE REGIONS OF BANGLADESH: AN IN-DEPTH ANALYSIS*. *8*, 15–35.
24. Mavroeidis, A., Roussis, I., & Kakabouki, I. (2022). The Role of Alternative Crops in an Upcoming Global Food Crisis: A Concise Review. *Foods*, *11*(22), 3584. https://doi.org/10.3390/foods11223584
25. Md Shahriar Kabir, Md Mahedi, A K M Kanak Pervez, Md Jahangir Alam, & Shabrin Jahan Shaili. (2025). Bibliometric analysis of "precision agriculture" in the Scopus database. *World Journal of Advanced Research and Reviews*, *25*(3), 1087–1098. https://doi.org/10.30574/wjarr.2025.25.3.0733
26. Mujeri, M. K., & Mujeri, N. (2021). Bangladesh's Rural Transformation. In M. K. Mujeri & N. Mujeri (Eds.), *Structural Transformation of Bangladesh Economy: A South Asian Perspective* (pp. 117–170). Springer. https://doi.org/10.1007/978-981-16-0764-6_5
27. Nabi, N., Gao, Q., & Rahman, T. (2018). *Microfinance Institutions of Bangladesh: The Effects of Credit Risk Management on Credit Performance*.
28. Nazu, S. B., Saha, S. M., Hossain, Md. E., Haque, S., & Khan, Md. A. (2022). Willingness to pay for adopting conservation tillage technologies in wheat cultivation: Policy options for small-scale farmers. *Environmental Science and Pollution Research*, *29*(42), 63458–63471. https://doi.org/10.1007/s11356-022-20306-x
29. Oluwole, O., Ibidapo, O., Arowosola, T., Raji, F., Zandonadi, R. P., Alasqah, I., Lho, L. H., Han, H., & Raposo, A. (2023). Sustainable transformation agenda for enhanced global food and nutrition security: A narrative review. *Frontiers in Nutrition*, *10*. https://doi.org/10.3389/fnut.2023.1226538

30. Sarker, M. R., Galdos, M. V., Challinor, A. J., & Hossain, A. (2021). A farming system typology for the adoption of new technology in Bangladesh. *Food and Energy Security*, *10*(3). https://doi.org/10.1002/fes3.287
31. Shabrin Jahan Shaili, Uttam Kumar Kabiraj, & Md Mahedi. (2025). Fungal Biocontrol in Agriculture: A Sustainable Alternative to Chemical Pesticides – A Comprehensive Review. *World Journal of Advanced Research and Reviews*, *26*(1), 2305–2316. https://doi.org/10.30574/wjarr.2025.26.1.0732
32. Shahbaz, P., Ul Haq, S., Abbas, A., Batool, Z., Alotaibi, B. A., & Nayak, R. K. (2022). Adoption of Climate Smart Agricultural Practices through Women Involvement in Decision Making Process: Exploring the Role of Empowerment and Innovativeness. *Agriculture*, *12*(8), 1161. https://doi.org/10.3390/agriculture12081161
33. Sharna, S. C., Anik, A. R., Rahman, S., & Salam, Md. A. (2022). Impact of Social, Institutional and Environmental Factors on the Adoption of Sustainable Soil Management Practices: An Empirical Analysis from Bangladesh. *Land*, *11*(12), 2206. https://doi.org/10.3390/land11122206
34. Suza, M., Warner, J., & Van Dijk, H. (2024). Climate, food (in)security and conflict in the Bangladesh delta: Myths and puzzles. *Environment and Security*, *2*(4), 525–547. https://doi.org/10.1177/27538796241244544
35. Uddin, M. S., Pervez, A. K., Kabir, M. S., & Mahedi, M. (2022). The Trend of Agribusiness Research Worldwide: A Bibliometric Analysis Based on the Scopus Database.
36. Wakweya, R. B. (2023). Challenges and prospects of adopting climate-smart agricultural practices and technologies: Implications for food security. *Journal of Agriculture and Food Research*, *14*, 100698. https://doi.org/10.1016/j.jafr.2023.100698
37. Zhu, H., He, X., Wang, X., & Long, P. (2024). Increasing Hybrid Rice Yield, Water Productivity, and Nitrogen Use Efficiency: Optimization Strategies for Irrigation and Fertilizer Management. *Plants*, *13*(12), 1717. https://doi.org/10.3390/plants13121717