



A Comparative Analysis of Digitization in the Agri-Food Sector -Innovations, Challenges, and Future Directions

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Abstract: The development of digitalization is a critical turn for global agri-food. Based on reviewing five key countries, namely Bangladesh, Kenya, India, Ghana, and Australia, this paper discusses and highlights the different models pursued and ensuing varied outcomes of integrating technology into agriculture. Digital tools are reshaping market access, supply chain efficiency, and sustainability- from e-commerce platforms in Bangladesh to climate adaptation policies in Australia. These challenges include gendered leaps in technology access, accessibility, and other regulatory barriers. This paper discusses the strengths and limitations of the current wave of digital initiatives through case studies, focusing on insights that seek to critically contribute to how technology can further revolutionize the agri-food sector. By addressing these challenges, countries can transform their agricultural sectors into globally competitive and resilient ones through inclusive digital transformation. Further, the paper concludes with ways in which future research should go to bridge gaps that exist in digital adoption for making agriculture sustainable and, in turn, for promoting inclusive growth.

Keywords: Digitalization, Agri-food industry, Agricultural technology, Smart agriculture, Smallholder farmers, Climate adaptation, Agricultural policy.

I. INTRODUCTION

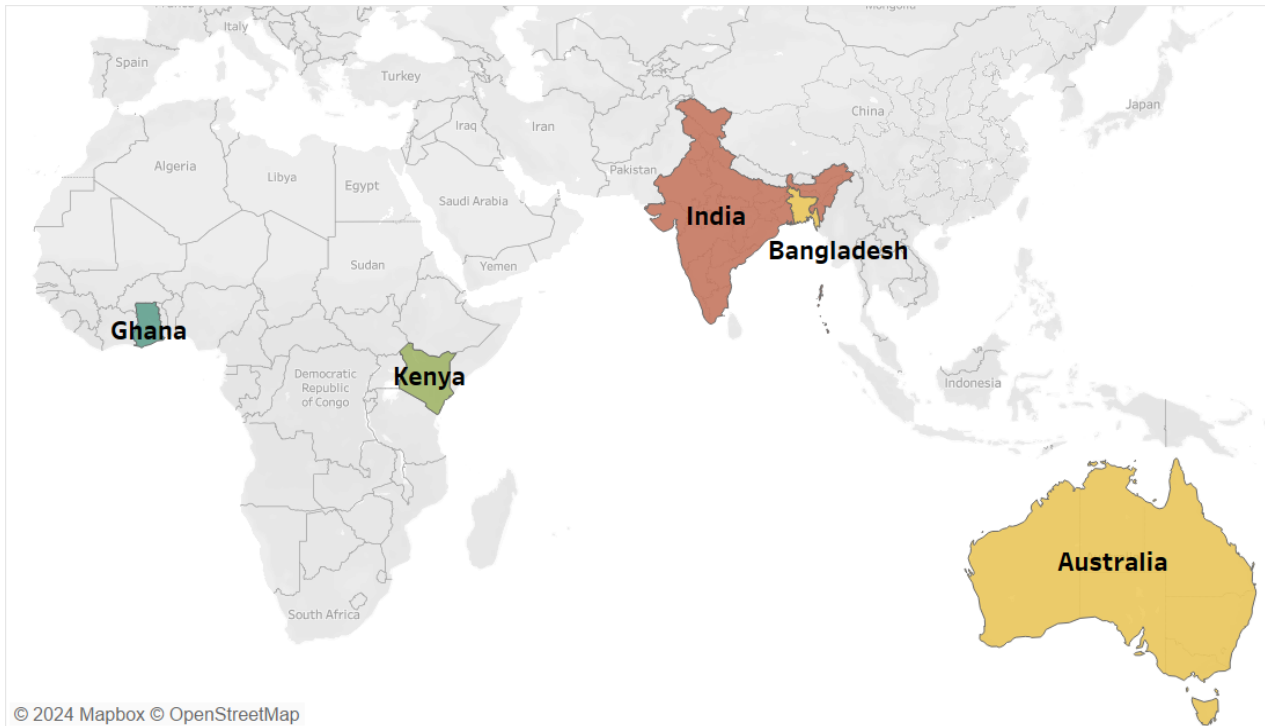
This revolution of traditional farming practices through innovative technologies along the value chain started almost a decade ago. Yet, this progress remains rudimentary and far from the immense potential the tech sector has managed to unlock. As a stretch, persistent barriers continue impeding meaningful transformation, hence holding back industry advancement and inhibiting it from realizing its full potential.

This transformation is key as agriculture confronts considerable challenges from climate change and food security, among other economic pressures. From electronic marketplaces to climate adaptation policies, there is a promise of better efficiency, increased access to wider markets, and improved productivity through digitization.

Previous studies have identified the importance of digital tools for solving these problems. Relevant research stressed that ICT enhances productivity and market connectivity (Ferroni & Zhou, 2018); the core issue was the poor post-harvest management infrastructure (Prabhakar, 2010), the positive livelihood impacts of digital tools in small-scale farming communities (Addison et al., 2024). Notwithstanding such advances, some critical bottlenecks-such as gender gaps, technological access, and incoherent regulatory regimes, hamper large-scale digital uptake in agriculture (Roberts, 2024; Shah, 2022). Consumers and regulatory bodies demand better traceability and transparency, which requires more advanced technological tools that many farms lack. Farms are becoming increasingly complex, and the lack of knowledge has become a barrier (Leppälä et al., 2012).

The presented paper reviews the status of digital agri-food initiatives in five countries, representing different stages of digital adoption: Bangladesh, Kenya, India, Ghana, and Australia- all of which face challenges related to solving traditional agricultural problems. By delivering an in-depth analysis of this case study, the paper hopes to understand how digitalization might overcome some traditional agricultural limitations and provide valuable insights into developing sustainable digital solutions. They are threefold: assessing the current state of digital adoption, determining crucial barriers and enablers, and providing recommendations for further research and policy development that can help bring about inclusive digital transformation in the agri-food sector.

Starting from the diverse regions, this paper intends to detail common themes and localized solutions to help inform global strategies for enhancing agricultural sustainability and resilience through digital means.



Note. Created using Tableau

Figure 1: World Map Highlighting Countries in Focus of the Review.

The secondary review and the core objectives of this study are encapsulated in two pivotal research questions (RQ):

RQ1: To what extent do new digital technologies improve the efficiency and resilience of agri-food value chains in various regions? What are the critical factors for successful adoption?

RQ2: What are the principal barriers to pervasiveness in digital adoption in the agro-food sector, and what set of mechanisms, in consideration of the above, should be used to overcome those obstacles with a view to inclusive and sustainable farming?

These questions provide the basis for deeper exploration into how digitalization is changing agriculture in practice to uncover actionable insights for practitioners and policymakers.

II. MATERIAL AND METHOD

This study employs a focused literature review across five countries—Bangladesh, Kenya, India, Ghana, and Australia—to assess digitalization in the agri-food sector. The literature was sourced from reputable databases, including ResearchGate and Scopus (Elsevier), focusing on peer-reviewed articles and case studies.

The review began by categorizing each country based on the type of digital initiatives, level of adoption, and challenges faced. Case studies were reviewed to highlight real-world examples of digital transformation in productivity, market access, and farmer livelihood through a comparative approach: analyzing technological infrastructure, policy support, and socio-economic challenges such as gender disparity and regulatory barriers.

This methodology ensured a thorough and balanced analysis to uncover the commonalities and divergences in digitalization efforts across the selected regions. Graphs, tables, and flowcharts were generated using Tableau and Excel to describe data and make comparisons among the reviewed countries.



III. LITERATURE REVIEW

Comprehensive Overview of Digitalization in the Agri-food Industry Across Various Countries

Bangladesh

Bangladesh has made significant advancements in agri-tech through companies like iFarmer, WeGro, and Fashol, which have revolutionized agricultural services by providing e-commerce platforms, smart agriculture initiatives, and real-time advice (Huda et al., 2023). The innovations have enhanced market access, improved supply chain efficiency, and offered financial support, leading to increased productivity and better market positioning for farmers (Diao et al., 2023).

Case Study: iFarmer's Integrated Services Platform

iFarmer exemplifies smart agriculture by offering a suite of services, including financing options, market access, and real-time agricultural advice. These services, such as those provided through Sofol and KriShop, are crucial for supporting farmers with loans for seeds, fertilizers, and other inputs. The platform's real-time advice helps farmers make informed decisions about crop management, resulting in improved supply chain efficiency and better financial outcomes (Huda et al., 2023).

Kenya

The rapid adoption of smartphones and internet-based services among Kenyan smallholders has transformed agricultural practices. Platforms like WhatsApp and Telegram are widely used for knowledge transfer, market coordination, and enhancing farmers' bargaining power (Hartmann et al., 2021). This digital shift has significantly improved access to agricultural knowledge and smallholder market outcomes (Diao et al., 2023).

Case Study: Smartphone Adoption Among Smallholders

A study by Hartmann et al. (2021) revealed that internet use among Kenyan smallholders increased due to the affordability and accessibility of smartphones. These devices have enabled farmers to access agricultural knowledge, engage in digital communication, and coordinate with buyers through marketing platforms, enhancing productivity and income.

Table 1

Knowledge Transfers and Coordination

<i>Type</i>	<i>Description</i>	<i>Enabled by Digital Connectivity</i>
<i>Vertical Knowledge</i>	Transfer of formal, scientific, or standardized knowledge from external sources.	Websites, government portals, e-extension services.
<i>Horizontal Knowledge</i>	Sharing of localized, practical knowledge between farmers.	Messaging apps, social networks, farmer networks.
<i>Market-based Coordination</i>	Coordination between farmers and buyers based on market conditions.	Digital marketing platforms, direct buyer-seller interactions.
<i>Captive Chains</i>	Close coordination and control by lead firms, often involving standardized practices.	Less influenced by digital connectivity, primarily offline.

Note. Source: Hartmann et al. (2020)(hartmann-et-al-2020-dig...). The types of knowledge transfers and coordination practices facilitated by digital connectivity.

India

India's agri-food industry has seen diverse digital initiatives, including ICT (Information and communication technology) projects like e-choupal and mKisan, the National Digital Livestock Mission (NDLM), and significant private sector investments in R&D. These initiatives have improved market access, livestock management, and agricultural productivity by providing real-time information and fostering innovative farming techniques (Ferroni & Zhou, 2018; Shah, 2022).

Case Studies:

- **National Digital Livestock Mission (NDLM):** Aims to create a connected ecosystem for livestock management, enhancing breeding, disease surveillance, and traceability through animal identification and mobile applications (National et al., 2024).



- **ICT in Agricultural Development:** Initiatives like e-choupal provide real-time market information, weather forecasts, and farming advisories, improving decision-making and bridging the information gap between urban and rural areas (Shah, 2022).

Figure 2

Flowchart: Application of ICT in Agriculture

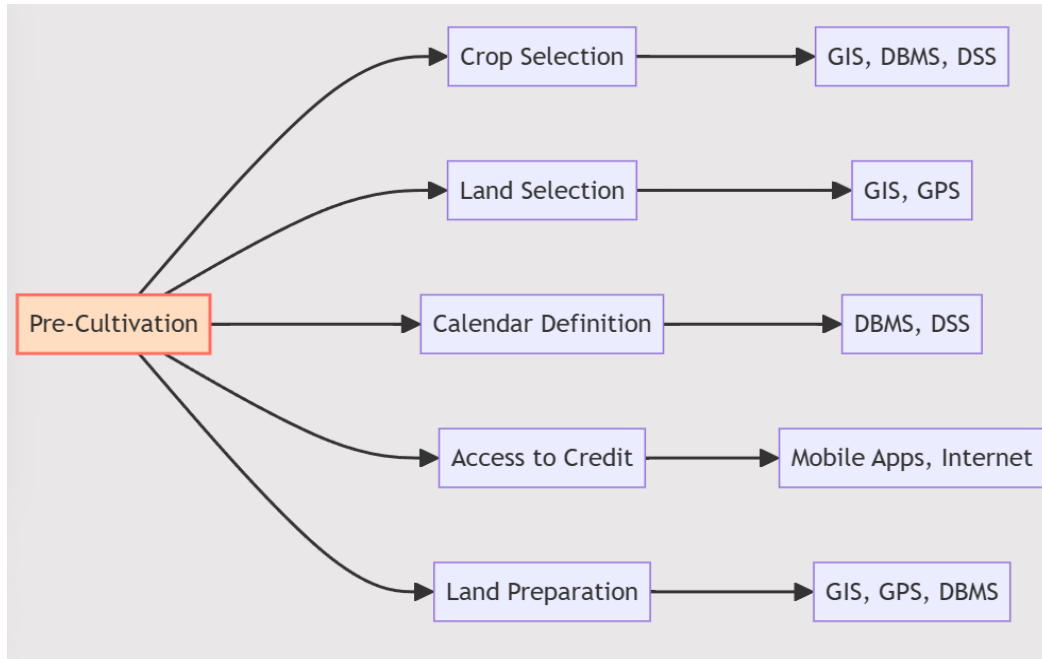


Figure 2a - ICT Application in Agriculture Pre-cultivation

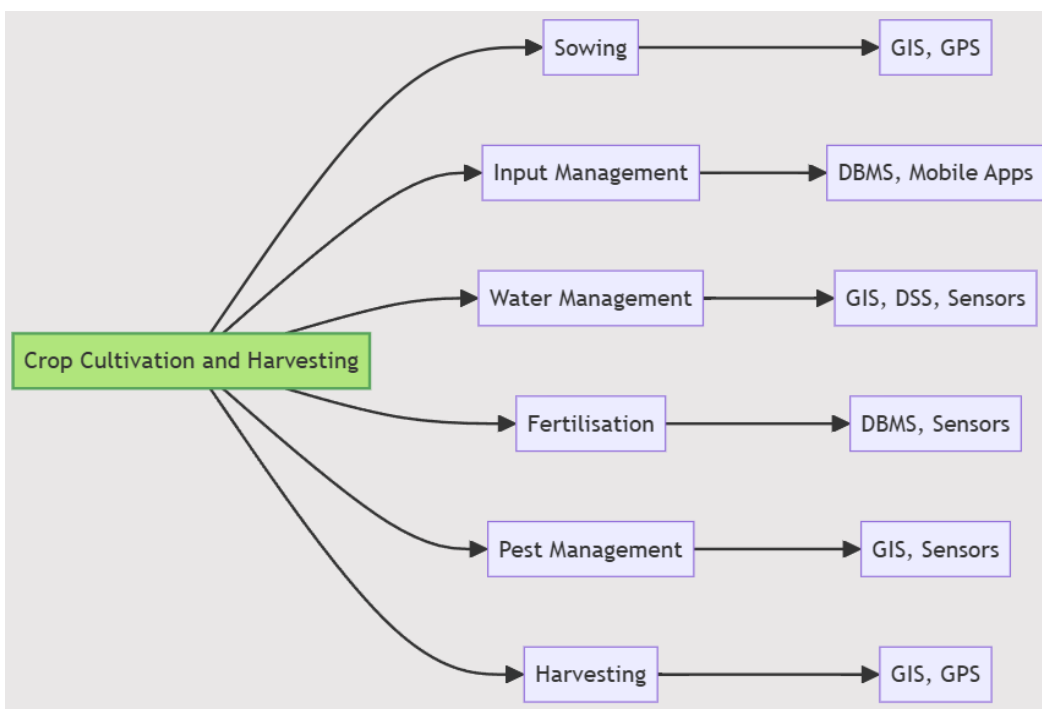
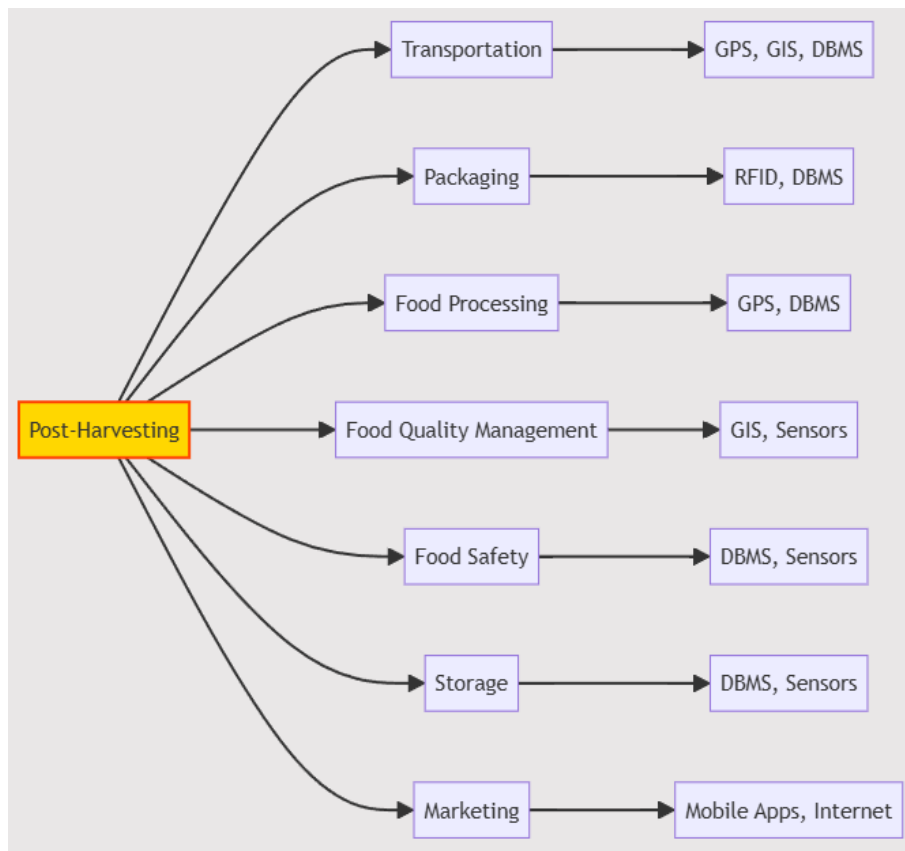


Figure 2b - ICT Application in Agriculture Cultivation



Note. ICT applications play a significant role in all phases of agricultural activities, from the pre-cultivation stage to the post-harvesting stage, using technologies like GIS, GPS, DBMS, DSS, and sensors.

Figure 2c - ICT Application in Agriculture Post-harvest

Digital solutions support the pre-cultivation stage and provide resources to farmers, including weather forecasts, soil condition information, and market trends. This helps the farmers make decisions for better efficiency at lower risks. ICT applications during the cultivation phase involve real-time monitoring and management. Sensors and data-driven insights optimize irrigation, pesticide sprays, and nutrient application, improving crop yield with increased resource efficiency. The same technologies link farmers to markets with e-commerce platforms and logistics support post-harvest.

- **Private Sector's Role in R&D:** Companies like ITC and TATA Chemicals have increased crop yields and farmer incomes by investing in agricultural research by developing and disseminating new seed varieties and sustainable farming practices (Ferroni & Zhou, 2018).

Ghana

Ghana's digitalization efforts have focused on improving smallholder farmers' livelihoods through mobile applications and ICT training programs. These initiatives have enhanced resource management and resilience against economic shocks, although gender disparity in technology usage remains challenging (Addison et al., 2024).

Case Study: Impact on Livelihood Outcomes

Addison et al. (2024) found a significant association between agricultural digitalization and improved livelihood outcomes for smallholder farmers in Ghana. Their study showed that farmers using digital tools experienced better agricultural production and health and reduced vulnerability to economic shocks. Factors like educational attainment and cooperative membership were crucial in driving digital adoption, and the study emphasized addressing gender disparities for inclusive digital transformation.

The impact on livelihood assets, outcomes, and gender disparities:



Table 2
Impact on Livelihood Assets

<i>Livelihood Asset</i>	<i>Users of Digital Technologies (%)</i>	<i>Non-users of Digital Technologies (%)</i>	<i>Improvement Difference (%)</i>
<i>Physical Assets</i>	28.1	5.39	22.71
<i>Financial Capital</i>	51.8	22.6	29.2
<i>Human Capital</i>	32.6	2.69	29.91
<i>Social Capital</i>	76.3	49.2	27.1
<i>Natural Capital</i>	17.9	2.36	15.54

Note. Source: Addison et al. (2024)

Table 2 illustrates the impact of digital technologies on livelihood assets, providing a comparative analysis of users and non-users of digital tools. As can be seen, the benefits of digital adoption are substantial, particularly in terms of physical and financial capital.

Table 3
Livelihood Outcomes

<i>Livelihood Outcome</i>	<i>Users of Digital Technologies (%)</i>	<i>Non-users of Digital Technologies (%)</i>	<i>Improvement Difference (%)</i>
<i>Agricultural Production</i>	58.5	18.2	40.3
<i>Health Status</i>	33.0	5.39	27.61
<i>Reduced Vulnerability</i>	21.0	8.42	12.58
<i>Average Monthly Income (GHC)</i>	471.96	385.29	86.67

Note. Source: Addison et al. (2024)(Exploring_the_impact_of...)

The livelihood outcomes demonstrate a clear improvement in agricultural production and health status, as well as reduced vulnerability for those adopting digital technologies.

Table 4
Digital Adoption Drivers

<i>Driver</i>	<i>Impact on Adoption of Digital Technologies</i>
<i>Education</i>	Higher educational attainment promotes adoption.
<i>Perception</i>	A positive perception of digitalization enhances adoption.
<i>Cooperative Membership</i>	Membership in cooperatives facilitates adoption.
<i>Number of Economically Active Household Members</i>	More active members increase the likelihood of adoption.
<i>Access to Reliable Electricity</i>	Reliable electricity significantly promotes adoption.
<i>Access to Internet</i>	Internet access is a strong enabler of adoption.
<i>Access to Mobile Money Services</i>	Mobile money services enhance adoption.



Note. Source: Addison et al. (2024)(Exploring_the_impact_of...). Overview of the factors driving digital adoption

Table 4 details the various factors that influence the adoption of digital technologies, with education and cooperative membership being strong drivers.

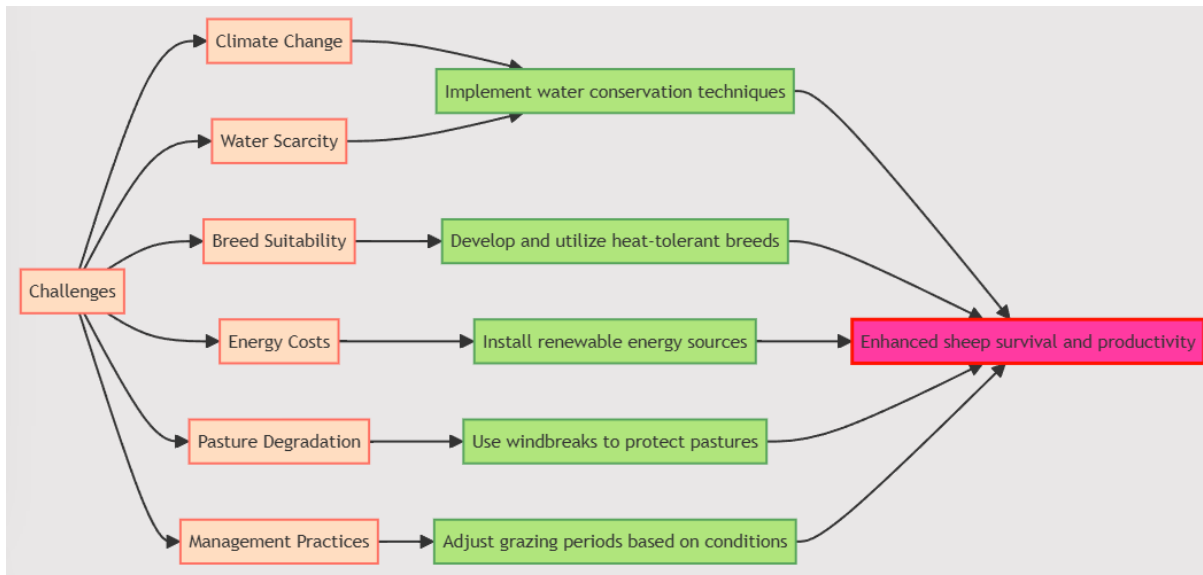
Australia

In Australia, climate change adaptation policies have been crucial in maintaining the viability of sheep farming. Government support programs and targeted adaptation measures, such as improved pasture management and water conservation, have significantly increased livestock survival rates and farm profitability (Roberts, 2024).

Case Study: Adaptation Measures in Sheep Farming

Roberts (2024) studied the impact of adaptation policy to climate change on Australian sheep farming. Indeed, targeted pasture management and water conservation methods have better survival and increased profitability. Support by the government in terms of resources and knowledge is considered important in implementing the various strategies among farmers.

Figure 3
Challenges and Recommendations for Sheep Farmers



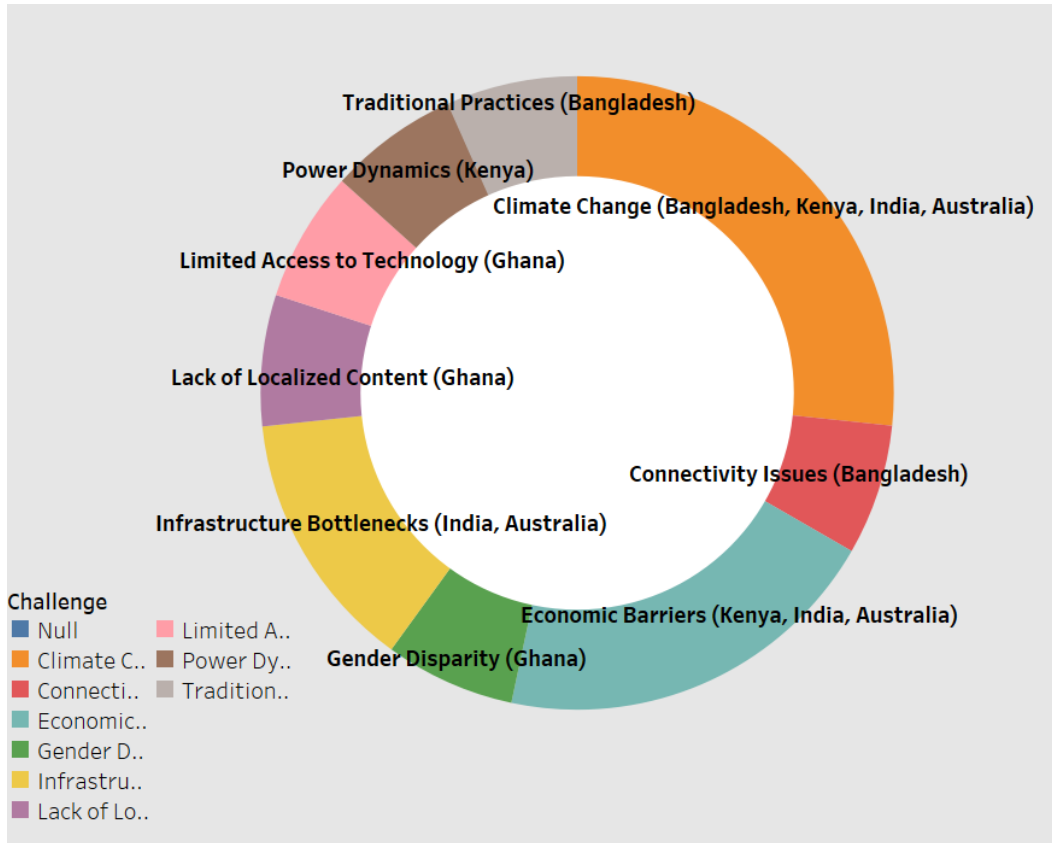
Note. Overview of the outcomes of different adaptation strategies, the challenges sheep farmers face, and recommended solutions.

Challenges

This section explores the unique challenges faced by various countries in adopting digital solutions within their agri-food sectors. While each region demonstrates distinct barriers, common themes such as infrastructure, economic limitations, and technological accessibility emerge, Figure 4 provides a visual comparison of these country-specific challenges, helping to identify patterns and potential areas for improvement.



Figure 4
Challenges Faced by Different Countries



Note. Created using Tableau

Digital Initiatives

Table 5
Overview of Digital Initiatives Taken by Different Countries

Country	Digital Initiatives	Challenges	Impacts
Bangladesh	E-commerce platforms (iFarmer, WeGro, Fashol)	Climate change, traditional practices, connectivity	Improved supply chain management, increased market access, better financial support
Kenya	Smartphones, internet services, WhatsApp, Telegram	Power dynamics, economic barriers	Increased access to knowledge, improved market coordination, enhanced bargaining power
India	ICT projects (e-choupal, mKisan, NDLM), private sector R&D	Infrastructure bottlenecks, economic barriers, climate	Enhanced market access, better livestock management, increased productivity, improved R&D
Ghana	Mobile applications, ICT training programs	Gender disparity, limited access, lack of localized content	Improved livelihood outcomes, enhanced physical, financial, human, social, and natural capital
Australia	Climate adaptation policies, government support programs	Infrastructure, economic barriers, climate variability	Higher survival rates of livestock, increased profitability, enhanced resilience



Digital initiatives across different countries showcase the benefits and challenges each nation faces. Building on this, Table 6 presents a comparative analysis that further dissects the factors contributing to or inhibiting the success of digitalization efforts.

Table 6
Integrated Comparative Table

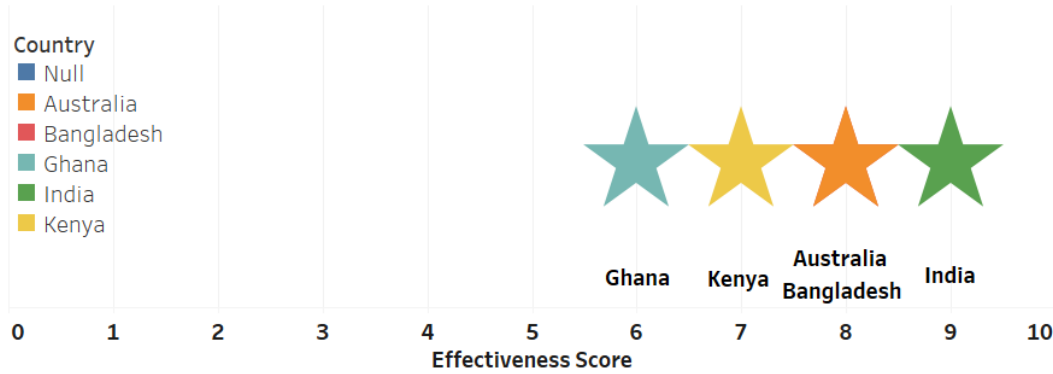
<i>Aspect</i>	<i>Bangladesh</i>	<i>Kenya</i>	<i>India</i>	<i>Ghana</i>	<i>Australia</i>
<i>Digital Infrastructure</i>	E-commerce platforms	Smartphones, internet services	ICT projects, private sector R&D	Mobile applications, ICT training programs	Climate adaptation policies, government support programs
<i>Education and Training</i>	Real-time advice through platforms	Knowledge transfer via WhatsApp, Telegram	Training programs as part of ICT projects	ICT training programs	Government and private sector training initiatives
<i>Supportive Policies</i>	Integration of financing and market access	Market coordination through digital platforms	Supportive ICT policies, National Digital Livestock Mission	Government and NGO initiatives	Government support programs
<i>Regulatory Frameworks</i>	Moderate supportive policies	Economic barriers, power dynamics in value chains	Strong supportive policies	Limited supportive policies	Supportive policies for climate adaptation
<i>Economic Barriers</i>	Mitigated by e-commerce platforms	Significant economic barriers	High costs of technology, access to financing	Limited access to technology due to economic barriers	Infrastructure and economic barriers
<i>Cultural Factors</i>	Traditional farming practices	Adoption of digital communication platforms	Use of traditional practices alongside digital methods	Gender disparity in technology usage	Traditional farming practices, adaptation to climate variability

Note. integrate the findings and comparisons into a comprehensive table.

Following the comparative insights outlined in Table 6, Figure 5 visually represents the effectiveness of digital initiatives across different countries, offering a quantitative perspective on the overall impact and success of these efforts.

Figure 5

Effectiveness of Digital Initiatives



Note. Each country is assigned an effectiveness score from 1 to 10 on a scale. This score represents how effective the digital initiatives have been in each country. A higher score indicates greater effectiveness.

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DISCUSSION

Synthesis of Findings from the Literature Review, Challenges, and Initiatives

Initiatives, challenges, and impacts shape digitalization within the agri-food industry in various countries. The literature review identifies significant developments of digital technologies that are increasingly adopted within agricultural production methods. Among other key identified initiatives, e-commerce platforms in Bangladesh, internet-based services in Kenya, ICT projects in India, mobile applications in Ghana, and climate adaptation policies in Australia are illustrative of the potential that digital tools can create to develop transformational changes within agri-food systems (Jha et al., 2020; Hartmann et al., 2021; Ferroni & Zhou, 2018).

However, there are many challenges related to such development. In general, resistance to change, regulatory obstacles, and technological accessibility hinder the large-scale uptake of these technologies (Doss, 2017). Connectivity challenges in Bangladesh add to the country-specific complexities, power dynamics in Kenya, infrastructure bottlenecks in India, gender disparity in Ghana, and economic barriers in Australia (Sulaiman & Hall, 2021)-all make the digitization process even more complicated.

The effectiveness of digital initiatives varies across regions. In Bangladesh, e-commerce platforms have improved supply chain management and market access, while Kenya's internet-based services have enhanced knowledge transfer and market coordination (Huda et al., 2023; Hartmann et al., 2021). India's ICT projects and private sector investments have boosted agricultural productivity and livestock management (Shah, 2022). Ghana's digitalization efforts are improving smallholder farmers' livelihoods, and Australia's adaptation policies are gradually increasing the resilience of sheep farming (Addison et al., 2024; Roberts, 2024).

Critical Analysis of the Current State of Digitalization in the Agri-food Industry

Table 7
Strengths and Weaknesses of Digitalization in the Agri-food Industry

Category	Key Point	References
STRENGTHS		
Enhanced Productivity	Digital technologies have led to increased agricultural productivity by providing farmers with real-time information, market access, and financial support.	Huda, Akter, & Safder (2023); Hartmann et al. (2021)
Improved Market Access	E-commerce platforms and digital communication tools have enabled farmers to reach broader markets and negotiate better terms.	Ferroni & Zhou (2018)



<i>Livelihood Improvement</i>	Digitalization has enhanced various aspects of farmers' livelihoods, including financial stability, access to resources, and resilience to environmental shocks.	Addison et al. (2024)
WEAKNESSES		
<i>Resistance to Change</i>	Farmers' reluctance to adopt new technologies due to a lack of awareness or trust remains a significant barrier.	Shah (2022)
<i>Regulatory Hurdles</i>	Inconsistent policies and regulations across regions hinder the seamless adoption of digital tools.	Roberts (2024)
<i>Technological Accessibility</i>	Limited access to reliable internet and digital tools, especially in rural areas, restricts the reach of digital initiatives.	Ferroni & Zhou (2018)

Note: This table summarizes the strengths and weaknesses of digitalization in the agri-food sector, highlighting the key points that influence its effectiveness across different regions.

Future Research

Outline Areas for Future Research

Impact of Digitalization on Smallholder Farmers:

The need of the hour is to understand precisely how digital technologies affect the productivity, income, and well-being of small-holder farmers in more in-depth research.

Gender Disparities in Digital Adoption:

Analyzing causes of gender inequalities in digital technology use and proposing measures for achieving inclusive digitalization.

Sustainability of Digital Initiatives:

The long-term sustainability and scalability of digital initiatives in agriculture have to be evaluated based on economic viability, environmental considerations, and social acceptance.

Highlight Gaps in the Current Knowledge

To address the specific needs and conditions of farmers in different regions, digital solutions must be more localized. These tools should be integrated with traditional agricultural knowledge, making them more relatable and relevant for farmers, particularly in overcoming gender disparities. Research shows that local adaptations are crucial to enhancing the effectiveness of digital tools, especially in regions with significant socio-cultural differences (Sulaiman & Hall, 2021). Traditional food supply chains have historically faced infrastructural challenges, such as outdated facilities and inadequate IT systems, which hinder communication and quality control (Hanf & Gagalyuk, 2009). Exploring how traditional agricultural practices can be combined with digital technologies to create more effective, culturally relevant solutions is essential (Doss, 2017). Additionally, assessing the economic and environmental trade-offs associated with adopting digital technologies in agriculture remains a crucial area for further investigation (Jha et al., 2021).

Suggest Directions for Further Investigation

Pilot Projects and Case Studies:

Pilot projects can be implemented first-hand to demonstrate the effectiveness of digital technologies in various agricultural settings. These efforts can provide practical insights into how different technologies perform in real-world contexts. The stakeholders can thus identify and share best practices that can be adapted across regions.

Collaborative Research Initiatives:

Research initiatives can that bring together governments, the private sector, academia, and farmer organizations. Such collaboration can help address common challenges in the digitalization of agriculture. The shared knowledge can thus be used to develop more effective solutions.



Policy Frameworks for Digital Agriculture:

Policy frameworks should be such that can support the adoption and scaling of digital technologies in agriculture. These frameworks should be designed to ensure inclusivity, sustainability, and adaptability to the diverse contexts in which agriculture operates, promoting long-term digital transformation.

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