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International Journal of Advanced Research in Food Science and Agriculture Technology

Journal homepage:
https://karyailham.com.my/index.php/fsat/index
ISSN: 3030-556X

Adoption Barriers and Willingness to Pay for Rapid Portable Germplasm Identification Technology among Smallholder Farmers: Insights from Sichuan, China

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ARTICLE INFO

Article history:
Received 28 July 2026
Received in revised form 31 August 2026
Accepted 3 September 2026
Available online 11 September 2026

Keywords:
Adoption barriers; willingness to pay; germplasm identification technology; smallholder farmers; agricultural innovation; Sichuan

ABSTRACT

The rapid advancement of agricultural biotechnology has increased the importance of rapid portable germplasm identification technology in supporting seed authentication, crop management, and sustainable agriculture among smallholder farmers. However, the adoption of such technology remains limited due to economic, technical, informational, and institutional barriers, while farmers' willingness to pay for the technology is still underexplored, particularly in Sichuan. Therefore, this study aims to develop an integrated framework explaining the relationship between adoption barriers, adoption intention, and willingness to pay for rapid portable germplasm identification technology among smallholder farmers. This conceptual study adopts a systematic literature review and theory integration approach by incorporating the Technology Acceptance Model, Diffusion of Innovations, and Contingent Valuation Method. The proposed framework identifies economic barriers, technical barriers, knowledge and information barriers, trust and risk perception, and institutional support as key factors influencing adoption intention and willingness to pay. The study concludes that successful diffusion of rapid portable germplasm identification technology requires affordability, training support, institutional facilitation, and trust-building mechanisms to encourage sustainable agricultural modernization among smallholder farmers.

1. Introduction

The agricultural sector is currently experiencing a profound transformation driven by rapid advancements in digital technologies, biotechnology, and precision farming systems. Emerging agricultural innovations such as artificial intelligence, biosensors, portable diagnostics, and smart farming technologies are increasingly reshaping traditional agricultural practices by enhancing

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productivity, improving resource efficiency, and supporting sustainable food production systems. Recent studies indicate that digital agricultural technologies have become essential instruments for addressing global challenges related to food security, climate change, declining biodiversity, and rural sustainability [3,9].

In recent years, portable agricultural diagnostic technologies have attracted substantial attention due to their ability to provide real-time, field-based information for farmers and agricultural stakeholders. These technologies enable rapid identification of crop diseases, soil conditions, and genetic materials without requiring sophisticated laboratory infrastructure. Within this technological landscape, rapid portable germplasm identification technology represents an emerging innovation with significant potential for supporting seed authentication, varietal verification, biodiversity conservation, and crop improvement initiatives. Germplasm identification is particularly important because accurate identification of plant genetic resources contributes to agricultural resilience, enhances breeding efficiency, and protects farmers against counterfeit or low-quality planting materials.

The increasing relevance of germplasm identification technologies is closely associated with the broader digital transformation of agriculture. According to Bertoglio *et al*., [3], the ongoing digital agricultural revolution integrates advanced technologies such as the Internet of Things (IoT), artificial intelligence, remote sensing, and digital diagnostics to modernize agricultural systems and improve sustainability outcomes. Similarly, recent studies emphasize that agricultural digitalization can improve decision-making processes, reduce production uncertainty, and optimize farm management efficiency among rural farming communities [5].

Despite the growing availability of agricultural technologies, adoption among smallholder farmers remains uneven and frequently constrained by economic, technical, institutional, and behavioral barriers. Smallholder farmers often encounter challenges such as limited financial capability, inadequate technical knowledge, insufficient training, low digital literacy, and uncertainty regarding technological benefits. Research by Cui *et al*., [9] demonstrates that factors such as technological complexity, compatibility, accessibility, and farmers' perceptions significantly influence the adoption of digital technologies in agricultural settings. Likewise, Manzoor *et al*., [29] argue that the adoption of digital agricultural technologies in developing regions is heavily shaped by infrastructural limitations, knowledge gaps, and institutional constraints.

In the context of Sichuan, the adoption of agricultural technologies has become increasingly important as China continues to promote rural revitalization and agricultural modernization strategies. Sichuan is recognized as one of China's major agricultural provinces, characterized by extensive smallholder farming activities and diverse crop genetic resources. The province plays a critical role in China's food production system and possesses substantial potential for integrating digital agricultural innovations into smallholder farming practices. Recent evidence from Sichuan indicates that digital agricultural technology services positively influence farmers' willingness to adopt digital production technologies by improving information accessibility, operational understanding, and economic cognition [19].

Although prior studies have extensively investigated the adoption of digital agriculture and smart farming technologies, limited scholarly attention has been devoted specifically to rapid portable germplasm identification technology. Existing studies predominantly focus on generalized digital agriculture adoption, precision farming systems, or smart agricultural services rather than portable germplasm diagnostic innovations. Furthermore, while willingness to adopt agricultural technologies has been widely explored, the issue of farmers' willingness to pay for emerging agricultural diagnostic technologies remains underexamined. According to the World Intellectual Property Organization, farmers' willingness to pay for new agricultural technologies is strongly influenced by perceived benefits, technological performance, learning requirements, and financial considerations.

More importantly, current literature rarely integrates adoption barriers with economic valuation perspectives within a unified theoretical framework. Most previous studies examine either technology adoption behavior or willingness to pay independently, resulting in limited understanding of how adoption barriers shape economic acceptance and commercialization potential among smallholder farmers. Consequently, there remains a significant theoretical and contextual gap concerning how economic barriers, technical complexity, knowledge limitations, trust perceptions, and institutional support collectively influence adoption intention and willingness to pay for portable germplasm identification technology among smallholder farmers in Sichuan.

Therefore, this study aims to develop an integrated conceptual framework examining the relationship between adoption barriers, adoption intention, and willingness to pay for rapid portable germplasm identification technology among smallholder farmers. By integrating perspectives from Technology Acceptance Model, Diffusion of Innovations, and economic valuation theory, this study seeks to contribute to the literature on agricultural innovation adoption, technology commercialization, and rural digital transformation. The findings are expected to provide valuable insights for policymakers, agricultural technology developers, extension agencies, and research institutions seeking to promote inclusive agricultural modernization and sustainable technology diffusion in rural farming communities.

The global agricultural sector is undergoing a significant transformation driven by the rapid advancement of digital technologies, precision farming systems, and agricultural biotechnology. This transformation is increasingly viewed as essential for addressing global challenges related to food security, climate change, resource scarcity, and sustainable agricultural production. Recent developments in digital agriculture have enabled farmers to utilize data-driven technologies, smart sensing systems, artificial intelligence, Internet of Things (IoT) devices, and remote monitoring tools to improve farming efficiency and decision-making processes. Scholars have argued that the digitalization of agriculture represents a major paradigm shift from conventional farming toward more intelligent, connected, and sustainable agricultural systems [3,6].

Digital agriculture refers to the integration of advanced digital technologies into agricultural production, management, and marketing systems. These technologies include cloud computing, satellite imaging, drones, mobile applications, blockchain systems, artificial intelligence, and smart sensors that facilitate real-time monitoring and farm optimization. According to Gumbi *et al.*, [20], digital agriculture ecosystems have increasingly become important in supporting smallholder farmers through improved access to information, precision decision-making, and market connectivity. Similarly, Hassim *et al.*, [22] emphasized that digital agriculture can enhance agricultural sustainability and rural development by improving productivity, operational efficiency, and resource management.

The emergence of precision agriculture has further accelerated the modernization of farming practices worldwide. Precision agriculture utilizes geospatial technologies, IoT devices, data analytics, and automated systems to optimize agricultural inputs and improve crop productivity while minimizing environmental impacts. Precision farming technologies enable site-specific crop management, efficient irrigation systems, automated fertilization, and early disease detection, thereby improving both economic and environmental outcomes. Recent studies indicate that precision agriculture technologies can substantially improve farm profitability and productivity by reducing labor costs, minimizing input waste, and enhancing crop quality [17]. Furthermore, the adoption of precision agriculture has been associated with more efficient resource utilization and improved sustainability outcomes in agricultural systems [34].

In addition to digitalization and precision farming, biotechnology adoption has become increasingly important in supporting agricultural innovation and resilience. Agricultural biotechnology encompasses a broad range of scientific techniques, including molecular diagnostics, genetic engineering, DNA-based identification systems, and biosensor technologies that improve crop productivity, disease management, and genetic resource conservation. Recent technological advancements have enabled the development of portable diagnostic tools capable of conducting rapid field-based germplasm identification, reducing dependence on laboratory-based testing and improving real-time agricultural decision-making. The integration of biotechnology with digital and precision agriculture systems has strengthened the ability of farmers and agricultural institutions to manage crop diversity, identify high-quality germplasm, and improve seed authenticity verification.

Despite the growing potential of digital agriculture, precision farming, and biotechnology adoption, the diffusion of these technologies among smallholder farmers remains uneven. Previous studies have highlighted that high implementation costs, technological complexity, limited infrastructure, inadequate digital literacy, and weak institutional support continue to hinder adoption among small-scale farmers [29,50]. Moreover, many smallholder farmers remain uncertain about the economic benefits and affordability of emerging agricultural technologies, influencing both adoption intention and willingness to pay.

Consequently, understanding how smallholder farmers perceive emerging agricultural technologies has become increasingly important for policymakers, agricultural researchers, and technology developers seeking to promote inclusive agricultural modernization. Within this context, rapid portable germplasm identification technology represents a promising innovation that combines elements of biotechnology, precision agriculture, and digital agriculture to support sustainable farming and agricultural resource management.

Germplasm identification technology has become increasingly important in modern agriculture due to its critical role in ensuring seed authenticity, conserving agricultural biodiversity, and enhancing crop productivity. Advances in portable and rapid identification technologies, including molecular diagnostics, biosensors, and DNA-based detection systems, have significantly improved the efficiency and accessibility of germplasm characterization and verification processes. These technologies are increasingly recognized as essential tools for supporting sustainable agricultural development and food security in both developed and developing agricultural systems.

One of the primary functions of germplasm identification technology is to ensure seed authentication and varietal purity. Accurate identification of crop varieties is essential for maintaining seed quality, preventing the circulation of counterfeit or mislabeled seeds, and ensuring that farmers receive genetically authentic planting materials. Recent studies have shown that improper seed identification may negatively affect crop quality, market value, and agricultural productivity, particularly among smallholder farming communities that rely heavily on seed performance for income generation. Phan Thi-Thu-Hong *et al.*, [36] emphasized that seed purity identification is a crucial component in evaluating seed quality because contamination or mixing with other varieties may significantly reduce crop yield and product quality.

Furthermore, portable germplasm identification technologies provide opportunities for real-time field verification, reducing farmers' dependence on laboratory-based testing systems that are often expensive, time-consuming, and inaccessible in rural areas. The growing integration of machine learning, biosensors, and genomic technologies into agricultural diagnostics is expected to further strengthen seed traceability and quality assurance mechanisms in modern agricultural supply chains.

Germplasm identification technology also plays a significant role in biodiversity conservation and the preservation of plant genetic resources. Agricultural biodiversity is increasingly threatened by climate change, habitat destruction, monoculture farming, and the replacement of traditional crop varieties with commercial high-yield cultivars. As a result, accurate identification and conservation of germplasm resources have become critical for safeguarding genetic diversity and ensuring long-term agricultural resilience.

Recent literature highlights that germplasm conservation is essential for maintaining global food security and protecting endangered or vulnerable plant species. Yadav and Yadav [49] noted that germplasm preservation supports the conservation of valuable genetic resources through both in situ and ex situ conservation approaches, including gene banks, cryopreservation, and DNA storage systems. Similarly, Prochnow *et al.*, [37] argued that plant genetic resources are crucial for crop improvement and biodiversity preservation because they preserve important genetic traits that may otherwise disappear during domestication and agricultural modernization.

In addition, Gepts [18] explained that biodiversity plays a fundamental role in crop improvement and agricultural sustainability, particularly in enhancing tolerance to environmental stress, pests, and diseases. The integration of advanced germplasm identification technologies therefore facilitates more accurate characterization, monitoring, and management of plant genetic resources, contributing to sustainable agricultural ecosystems and climate resilience.

Another important contribution of germplasm identification technology is its potential to improve crop productivity and agricultural efficiency. Accurate identification of superior germplasm enables farmers, breeders, and agricultural institutions to select crop varieties with desirable characteristics such as high yield potential, drought tolerance, pest resistance, and improved nutritional quality. This is particularly important in smallholder farming systems where productivity improvements directly influence household income, food availability, and rural livelihoods.

Recent studies suggest that improved access to genetically diverse and properly identified germplasm resources can significantly strengthen agricultural resilience and productivity. Wang et al. (2026) reported that plant core germplasm collections contribute substantially to crop improvement, efficient resource management, and sustainable agricultural innovation through the application of modern genomic and predictive breeding technologies. Likewise, Wambugu et al. highlighted that improved farmer access to conserved germplasm resources may enhance food security and climate resilience by enabling farmers to identify and adopt crop varieties with preferred agronomic traits.

Moreover, the emergence of portable diagnostic technologies allows farmers to make faster and more informed decisions regarding seed selection and crop management under dynamic environmental conditions. Such technologies may reduce production uncertainty, improve resource allocation, and strengthen the adaptive capacity of smallholder farming systems in regions experiencing increasing climate variability.

Smallholder agriculture continues to play a fundamental role in China’s rural economy, food security, and agricultural sustainability. In Sichuan, agriculture remains one of the province’s most strategically important economic sectors due to its large rural population, diverse agroecological conditions, and extensive crop production activities. Sichuan is widely recognized as one of China’s major agricultural provinces, contributing significantly to the national production of rice, maize, vegetables, rapeseed, and livestock products. The province’s complex topography and rich biodiversity also make it an important region for germplasm conservation and agricultural genetic resource management.

Smallholder farmers dominate agricultural production systems in Sichuan, where farming activities are often characterized by fragmented landholdings, labor-intensive cultivation practices, and relatively limited access to advanced agricultural technologies. Despite the increasing modernization of China’s agricultural sector, many smallholder farmers continue to face structural constraints such as limited financial resources, inadequate technical knowledge, and restricted access to digital agricultural infrastructure. These limitations may hinder the adoption of emerging agricultural innovations, particularly technologies requiring technical competency and initial investment costs.

In recent years, the Chinese government has accelerated efforts to modernize agriculture through digital transformation, smart farming initiatives, and rural revitalization strategies. The integration of technologies such as artificial intelligence, Internet of Things (IoT), big data analytics, remote sensing, and portable diagnostic tools has become increasingly important in supporting agricultural productivity and sustainability. According to recent national policy developments, China’s smart agriculture strategy aims to strengthen digital agricultural infrastructure, improve agricultural efficiency, and promote technological innovation across farming systems.

The modernization of agriculture in Sichuan has also been supported by broader national initiatives emphasizing agricultural digitalization and precision farming. Emerging technologies are increasingly viewed as essential mechanisms for improving crop management, enhancing productivity, reducing operational costs, and supporting food security objectives. Digital agriculture technologies additionally provide opportunities for improving traceability, varietal authentication, and germplasm management, which are becoming increasingly important in the context of climate change, biodiversity preservation, and seed quality assurance.

Nevertheless, the transition toward technology-driven agriculture among smallholder farmers remains uneven. The adoption of advanced agricultural technologies is often influenced by economic affordability, perceived complexity, institutional support, and farmers’ perceptions regarding the usefulness and reliability of technological innovations. Consequently, understanding the barriers affecting technology adoption and farmers’ willingness to pay for emerging agricultural diagnostic technologies is essential for promoting inclusive agricultural modernization in Sichuan and other rural regions of China.

Despite the rapid advancement of digital agriculture and portable diagnostic technologies, the adoption rate of emerging agricultural technologies among smallholder farmers remains relatively low in many developing agricultural regions. Smallholder farmers often face structural and behavioral constraints that limit their ability and willingness to adopt innovative agricultural solutions. Recent studies have shown that economic limitations, technological complexity, inadequate infrastructure, and insufficient technical knowledge continue to hinder the diffusion of digital agricultural technologies among rural farming communities [12].

The issue of low adoption is particularly concerning because emerging agricultural technologies are increasingly viewed as essential tools for improving productivity, resource efficiency, crop monitoring, and agricultural sustainability. However, many smallholder farmers remain hesitant to adopt such technologies due to uncertainty regarding their practical usefulness, operational reliability, and long-term economic benefits. Zhang *et al*., [54] found that technology acceptance among small rural farmers is strongly influenced by perceived usefulness, ease of use, and trust in the technology itself. Similarly, Cimino *et al*., [7] emphasized that farmers’ behavioral intention to adopt digital agricultural platforms is shaped by perceived risks, innovation readiness, and the overall value proposition offered by the technology.

Another major research problem relates to uncertain market acceptance of emerging agri-technologies. While technological innovations continue to evolve rapidly, commercialization success depends heavily on farmers’ readiness to integrate these technologies into daily agricultural practices. Existing literature indicates that many digital agricultural tools experience limited field penetration because farmers are uncertain about the technology’s compatibility with local farming conditions, expected economic returns, and long-term operational sustainability. Furthermore, farmers may resist adopting technologies that require significant changes to traditional farming practices or demand advanced digital skills that are not widely available in rural communities.

Affordability concerns also represent a critical barrier influencing technology adoption and willingness to pay among smallholder farmers. Many emerging agricultural technologies involve substantial acquisition, maintenance, training, and operational costs that may exceed the financial capacity of resource-constrained farmers. Studies on digital agricultural services and mobile agricultural applications have shown that although farmers may perceive technological innovations positively, their willingness to pay often declines as the financial burden increases [30]. Research further suggests that poorer farming households may be unable to sustain recurring subscription or operational costs associated with advanced agricultural technologies, thereby limiting widespread adoption [30].

In the context of Sichuan, these concerns become increasingly important as agricultural modernization and rural revitalization policies continue to encourage the integration of digital and biotechnology-based agricultural innovations into smallholder farming systems. Despite policy support and technological advancement, limited scholarly attention has been given to understanding how adoption barriers influence farmers' willingness to pay for rapid portable germplasm identification technology. Existing studies primarily focus on general agricultural digitalization rather than portable germplasm diagnostic technologies specifically. Consequently, there remains a significant theoretical and practical gap in understanding the factors shaping adoption intention and economic acceptance of such technologies among smallholder farmers.

Rapid portable germplasm identification technology refers to field-deployable diagnostic tools that allow plant genetic materials, cultivars, or seed varieties to be identified quickly outside conventional laboratory settings. In agricultural systems, such technology is increasingly relevant because accurate germplasm identification supports varietal authentication, seed quality control, crop improvement, biodiversity conservation, and protection against counterfeit planting materials. Recent advances in portable diagnostics have shifted molecular testing from centralized laboratories toward field-based applications, enabling faster decision-making for farmers, breeders, extension officers, and seed certification agencies.

One important component of this technology is handheld diagnostics, particularly portable sequencing and field-based molecular testing platforms. Portable nanopore sequencing has been widely discussed as a major advancement because it allows real-time DNA analysis with smaller equipment and shorter turnaround time compared with conventional sequencing systems. Parker et al. (2017) demonstrated that real-time nanopore sequencing could be used for field-based identification of closely related plant species, showing the potential of portable sequencing for plant identification beyond laboratory environments. More recent studies further highlight that nanopore sequencing is increasingly applied in plant diagnostics because of its capacity for rapid, on-site molecular analysis.

Another important technological pathway is the use of biosensors, including electrochemical biosensors, microfluidic platforms, lab-on-a-chip systems, and smartphone-integrated diagnostic devices. Biosensors are designed to detect specific biological or chemical signals and convert them into measurable outputs, making them suitable for rapid agricultural diagnostics. Yadav and Yadav [49] emphasized that portable plant diagnostic systems increasingly combine biosensors, nucleic acid amplification, immunoassays, handheld analyzers, and smartphone-based platforms to support rapid on-site detection in agricultural settings. Although many biosensor applications are currently concentrated on plant pathogen detection, their underlying principles are highly relevant to germplasm identification because both require rapid, sensitive, and field-compatible biological recognition systems.

The third foundation of rapid portable germplasm identification is molecular identification, particularly DNA barcoding, molecular markers, PCR-based assays, loop-mediated isothermal amplification, and next-generation sequencing. DNA barcoding uses short standardized genetic regions to distinguish species, cultivars, or genetic lines. Rani et al. (2025) explained that DNA barcoding has become an important tool for species identification, biodiversity assessment, conservation, agriculture, and quality authentication. Similarly, Samarina et al. (2025) highlighted the importance of DNA barcoding for cultivar identification and intraspecific diversity analysis, especially for tracking valuable cultivars and managing germplasm collections. These molecular tools are especially important in smallholder farming contexts because they can help verify seed authenticity, reduce uncertainty in variety selection, and support more reliable access to improved genetic materials.

In the context of this study, rapid portable germplasm identification technology is not viewed merely as a scientific tool, but as an agricultural innovation whose value depends on farmer acceptance. For smallholder farmers in Sichuan, China, the practical benefits may include faster identification of crop varieties, improved confidence in seed quality, reduced dependence on distant laboratories, and better alignment between planting decisions and local agroecological conditions. However, the successful diffusion of this technology depends on whether farmers perceive it as affordable, useful, easy to operate, reliable, and institutionally supported. Therefore, understanding handheld diagnostics, biosensors, and molecular identification provides the technological foundation for examining adoption barriers and willingness to pay.

Smallholder farmers play a central role in agricultural production, rural livelihoods, and food security, yet their adoption of new agricultural technologies often remains uneven. Unlike large commercial farms, smallholders frequently operate under tighter financial, informational, and institutional constraints, which shape how they evaluate unfamiliar technologies. Recent studies show that adoption decisions are not determined only by technical efficiency, but also by farmers' perceptions of cost, usability, risk, trust, and expected economic benefit [12,24].

Innovation resistance is particularly relevant when technologies are unfamiliar, complex, or perceived as inconsistent with existing farming practices. Chindasombatcharoen et al. (2024) argued that psychological barriers, including mistrust, perceived effort, uncertainty, and resistance to change, can prevent smallholder farmers from adopting agricultural innovations even when potential benefits exist. This is important for rapid portable germplasm identification technology because smallholders may question the reliability of field-based diagnostic results, the relevance of genetic identification to everyday farming decisions, and the practicality of using such devices without technical assistance.

Resource limitations further constrain technology adoption among smallholder farmers. Digital and advanced agricultural technologies often require financial investment, technical knowledge, connectivity, training, and after-sales support. Dibbern *et al.*, [12] found that economic conditions, technological infrastructure, technical knowledge, and reliability concerns are key barriers to digital agriculture adoption. Similarly, Hoang and Tran [24] reported that smallholders with higher education, larger farms, training exposure, and stronger extension contact were more likely to adopt digital agricultural technologies. These findings suggest that limited affordability, low technical literacy, and weak institutional support may reduce smallholders' readiness to adopt portable germplasm identification tools.

Risk aversion also influences adoption behaviour. Smallholder farmers are often cautious toward technologies that involve uncertain returns, unfamiliar procedures, or possible financial loss. Spiegel *et al.*, [43] show that risk aversion affects both the timing and scale of agricultural technology adoption, while Kebede [26] demonstrates that risk preferences can shape adoption gaps among smallholder farmers. In China, Mao, Quan, and Fu (2023) found that risk aversion and loss aversion significantly inhibited farmers' adoption of low-carbon agricultural technologies. Therefore, for smallholder farmers in Sichuan, perceived uncertainty regarding accuracy, cost recovery, and practical usefulness may reduce adoption intention and willingness to pay for rapid portable germplasm identification technology.

Overall, smallholder technology adoption should be understood as a behavioural, economic, and institutional process rather than a purely technical decision. In the context of this study, innovation resistance, resource limitations, and risk aversion provide a strong basis for examining how adoption barriers influence adoption intention and, subsequently, willingness to pay.

Adoption intention and willingness to pay represent two distinct yet sequential stages of farmers' decision-making toward emerging agricultural technologies. Adoption intention reflects behavioural readiness to use an innovation, whereas willingness to pay represents the economic commitment to acquire that innovation. Although these constructs are closely related, behavioural acceptance does not necessarily translate into monetary commitment, particularly among smallholder farmers operating under financial constraints. Consequently, understanding the relationship between adoption intention and willingness to pay is essential for explaining not only whether farmers are willing to adopt a technology, but also whether they are prepared to invest financial resources for its acquisition.

From the perspective of the Technology Acceptance Model (TAM), farmers first evaluate whether a technology is useful and easy to use before developing a positive behavioural intention [11]. Behavioural intention therefore represents farmers' psychological acceptance of an innovation. However, adoption intention alone cannot determine market success because farmers must subsequently assess whether the expected benefits justify the financial investment required to obtain the technology. This transition from behavioural acceptance to economic commitment represents an important stage that conventional technology adoption theories do not explicitly address.

The Contingent Valuation Method (CVM) provides the economic rationale for this transition by explaining how individuals assign monetary value to innovations based on their perceived benefits and expected utility. Once farmers develop a favourable intention to adopt rapid portable germplasm identification technology, they are more likely to evaluate the technology positively, perceive greater value in its application, and demonstrate stronger willingness to pay. Conversely, even when behavioural intention exists, willingness to pay may remain low if farmers perceive the technology as unaffordable or economically risky. Thus, willingness to pay reflects the final economic manifestation of behavioural acceptance rather than an independent decision.

Recent agricultural technology studies support this sequential relationship. Research has shown that farmers who perceive digital agricultural technologies as useful and beneficial exhibit stronger behavioural intention, which subsequently increases their willingness to invest in agricultural innovations through higher perceived value, expected productivity gains, and confidence in future returns [16,19,30]. Similarly, commercialization studies suggest that behavioural intention functions as an important precursor to economic valuation because positive perceptions reduce uncertainty and strengthen consumers' readiness to allocate financial resources toward new technologies.

Accordingly, this study conceptualises adoption intention as the behavioural mechanism through which multidimensional adoption barriers influence willingness to pay. Economic barriers, technical barriers, knowledge and information barriers, trust and risk perception, and institutional support first shape farmers' intention to adopt rapid portable germplasm identification technology. Subsequently, stronger adoption intention increases the likelihood that farmers will assign positive economic value to the technology and express willingness to pay for its acquisition. This sequential process integrates behavioural acceptance with economic valuation, providing a more comprehensive explanation of technology commercialization among smallholder farmers.

Willingness to pay (WTP) refers to the maximum value or amount that individuals are prepared to sacrifice in exchange for obtaining a product, service, or innovation that is perceived to provide utility or benefits. Within the context of agricultural innovation, WTP has become an important economic indicator for evaluating farmers’ acceptance of emerging technologies, particularly when such technologies require financial investment and behavioral adaptation. In studies related to agricultural technology adoption, WTP is frequently used to assess the commercial feasibility, affordability, and market potential of innovations introduced to farming communities.

From an economic valuation perspective, WTP reflects farmers’ subjective assessment of the expected benefits associated with technology adoption relative to its perceived costs. Smallholder farmers are more likely to demonstrate positive willingness to pay when they perceive that a technology can improve productivity, reduce uncertainty, enhance crop quality, or generate long-term economic returns. Conversely, high acquisition costs, uncertainty regarding performance, and limited financial capacity may reduce their willingness to invest in unfamiliar agricultural technologies. Recent studies have emphasized that economic considerations remain one of the strongest determinants influencing smallholder farmers’ adoption decisions toward digital and precision agricultural technologies.

In addition to economic affordability, price acceptance plays a significant role in shaping farmers’ willingness to pay. Price acceptance refers to the degree to which individuals perceive the price of a technology as reasonable, fair, and justified by its expected value. Farmers’ acceptance of pricing structures is often influenced by their income level, perceived usefulness of the technology, and confidence in the reliability of technological outcomes. Technologies perceived as overly expensive relative to expected benefits are less likely to achieve widespread adoption among smallholder farmers, particularly in developing agricultural regions where financial constraints are substantial.

Perceived value further strengthens the relationship between technology adoption intention and willingness to pay. Perceived value refers to the overall evaluation of the utility and benefits derived from a technology after comparing expected gains with anticipated sacrifices. In the context of rapid portable germplasm identification technology, farmers may perceive value through improved seed authentication, reduction of counterfeit planting materials, enhanced crop management decisions, and increased agricultural productivity. When farmers perceive that the benefits of the technology outweigh the associated financial and operational costs, their willingness to pay is likely to increase.

The present study grounds the willingness-to-pay construct in the Contingent Valuation Method (CVM), which is widely used in economic valuation studies to estimate individuals’ monetary valuation for goods, services, or technologies that may not yet have established market prices. CVM enables researchers to measure hypothetical market preferences by asking respondents directly about the amount they are willing to pay for a proposed innovation or benefit. Recent literature has demonstrated the growing application of CVM in evaluating agricultural technologies, environmental resources, and digital innovations among farming communities.

Although China has accelerated agricultural modernization through initiatives such as Digital Agriculture and the Rural Revitalization Strategy, empirical research conducted in Sichuan has primarily concentrated on farmers' adoption of digital agricultural services, green production technologies, precision agriculture, and digital information platforms. For example, Gong *et al*., [19] demonstrated that digital agricultural technology services improve farmers' willingness to adopt digital production technologies by enhancing information accessibility and technological cognition. Similarly, Zhang *et al*., [54] reported that cooperative participation and institutional support positively influence agricultural technology adoption among farmers in Sichuan, while more recent studies have examined the roles of digital literacy, innovation capability, and environmental sustainability in promoting agricultural modernization. Collectively, these studies have substantially advanced understanding of digital agriculture adoption within the province but remain largely focused on production-oriented technologies rather than biotechnology-based diagnostic innovations.

More specifically, the existing literature provides little evidence regarding farmers' acceptance of rapid portable germplasm identification technology. Unlike conventional digital farming tools that support crop management or production efficiency, rapid portable germplasm identification technology enables field-based verification of seed authenticity, varietal identification, biodiversity conservation, and genetic resource management. These functions are particularly relevant in Sichuan because the province possesses rich crop genetic diversity, extensive smallholder farming systems, and strategic importance for national agricultural production. Despite these characteristics, previous studies have not examined how smallholder farmers perceive this emerging biotechnology, the barriers affecting its adoption, or the factors influencing their willingness to invest financially in such technology.

Another important limitation concerns the separation between behavioural and economic perspectives. Existing studies conducted in Sichuan predominantly explain farmers' technology adoption using behavioural constructs such as perceived usefulness, accessibility, institutional support, and digital capability. Conversely, willingness-to-pay research has generally focused on pricing, subsidies, or economic valuation without explicitly considering the behavioural mechanisms that precede financial commitment. Consequently, there remains limited understanding of how adoption barriers influence behavioural intention and how behavioural intention subsequently translates into willingness to pay for an emerging agricultural biotechnology.

Therefore, the present study addresses three interconnected research gaps. First, it extends the literature beyond general digital agriculture by focusing specifically on rapid portable germplasm identification technology. Second, it advances current knowledge by integrating behavioural and economic perspectives within a single conceptual framework linking adoption barriers, adoption intention, and willingness to pay. Third, it contributes context-specific knowledge by developing a framework tailored to the characteristics of Sichuan's smallholder farming systems, thereby providing a stronger theoretical basis for technology commercialization, agricultural extension programmes, and evidence-based policy development.

Accordingly, this study contributes to the literature in three ways. First, it extends agricultural technology adoption research by focusing on rapid portable germplasm identification technology, an underexplored agricultural biotechnology. Second, it integrates the Technology Acceptance Model, Diffusion of Innovations, and the Contingent Valuation Method into a unified framework explaining the progression from adoption barriers to behavioural intention and willingness to pay. Third, it provides a context-specific framework for Sichuan's smallholder farming sector, offering theoretical guidance for technology commercialization, agricultural extension, and policy formulation.

2. Methodology

The Technology Acceptance Model has been widely recognized as one of the most influential theoretical frameworks for explaining individual acceptance and usage intention toward new technologies. The model proposes that users' behavioral intention to adopt a technology is primarily influenced by two key constructs, namely perceived usefulness and perceived ease of use. Perceived usefulness refers to the extent to which individuals believe that a technology can improve their performance or productivity, whereas perceived ease of use reflects the degree to which the technology is perceived as simple and effortless to operate.

Within the agricultural context, the Technology Acceptance Model has increasingly been applied to explain farmers' adoption intention toward emerging agricultural technologies, including smart farming systems, precision agriculture, agricultural drones, and digital agricultural platforms. Recent studies have demonstrated that perceived usefulness and ease of use significantly influence farmers' intention to adopt agricultural innovations, particularly when technologies are associated with improved productivity, reduced operational uncertainty, and enhanced farming efficiency.

In the context of rapid portable germplasm identification technology, the Technology Acceptance Model is particularly relevant because smallholder farmers are likely to evaluate the technology based on its practical usefulness, operational simplicity, and potential contribution to crop management and seed authentication. Technologies perceived as complicated, difficult to operate, or lacking clear economic benefits may reduce farmers' intention to adopt them. Conversely, technologies perceived as beneficial and user-friendly are more likely to stimulate positive adoption intention. Therefore, the Technology Acceptance Model provides a strong theoretical foundation for explaining the mediating role of adoption intention in this study.

The Diffusion of Innovations explains how new ideas, technologies, and innovations spread across social systems over time. According to Rogers, the adoption process is influenced by several innovation characteristics, including relative advantage, compatibility, complexity, trialability, and observability. The theory emphasizes that individuals are more likely to adopt innovations that are perceived as advantageous, compatible with existing practices, and easy to understand and implement.

The Diffusion of Innovations theory has been extensively utilized in agricultural innovation research because farming communities often rely on social learning, peer influence, and experiential evaluation before adopting new technologies. Prior studies have highlighted that adoption barriers such as technological complexity, lack of compatibility with existing farming systems, insufficient technical knowledge, and institutional limitations significantly influence farmers' innovation decisions.

In relation to rapid portable germplasm identification technology, smallholder farmers in Sichuan may face multiple barriers during the innovation adoption process. Economic constraints may limit affordability, technical complexity may reduce confidence in technology usage, and inadequate institutional support may weaken farmers' willingness to experiment with new diagnostic tools. Furthermore, trust and perceived risk may influence whether farmers perceive the technology as reliable and beneficial for agricultural decision-making. Consequently, the Diffusion of Innovations theory provides a suitable theoretical basis for understanding the multidimensional adoption barriers examined in this study.

The Contingent Valuation Method is widely employed in economic and environmental research to estimate individuals' willingness to pay for goods, services, or innovations that may not yet exist within conventional markets. The method evaluates how individuals assign monetary value to a product or service under hypothetical market conditions, allowing researchers to measure perceived economic value and acceptance.

In agricultural research, the Contingent Valuation Method has increasingly been applied to assess farmers' willingness to pay for sustainable agricultural technologies, eco-friendly farming systems, digital agricultural innovations, and environmental management practices. Existing studies indicate that willingness to pay is influenced by perceived usefulness, expected economic returns, affordability, trust, and awareness regarding the potential benefits of the innovation.

The present study adopts the Contingent Valuation Method as the theoretical basis for examining smallholder farmers' willingness to pay for rapid portable germplasm identification technology. Since the technology represents an emerging agricultural innovation with potential commercial application, understanding farmers' valuation behavior is essential for determining market acceptance, pricing feasibility, and commercialization strategies. The Contingent Valuation Method therefore provides a suitable framework for explaining how adoption intention may translate into economic willingness to pay.

Understanding smallholder farmers' acceptance of rapid portable germplasm identification technology requires a theoretical perspective that simultaneously explains technology acceptance, innovation diffusion, and economic valuation. Although the Technology Acceptance Model (TAM), Diffusion of Innovations (DOI), and the Contingent Valuation Method (CVM) have each been widely applied in agricultural technology research, each addresses only part of the decision-making process. Integrating these complementary perspectives therefore provides a more comprehensive explanation of how farmers progress from recognising an innovation to forming adoption intentions and ultimately making economic commitments through willingness to pay.

The Technology Acceptance Model (TAM) provides the behavioural foundation of the proposed framework by explaining how farmers develop intentions to adopt a new technology through cognitive evaluations of its usefulness and ease of use [11]. In agricultural settings, TAM has consistently demonstrated that behavioural intention is the strongest predictor of technology adoption because farmers first evaluate whether an innovation improves productivity while remaining sufficiently simple to operate. Recent studies further confirm that perceived usefulness and perceived ease of use remain fundamental determinants of farmers' acceptance of digital and smart agricultural technologies.

However, TAM alone provides only a partial explanation because it primarily focuses on individual cognitive perceptions while giving limited attention to the broader innovation environment in which technology adoption occurs. Smallholder farmers frequently encounter external constraints including affordability, compatibility with existing farming practices, institutional support, technical knowledge, and perceived risk that extend beyond the original TAM constructs. These contextual conditions are particularly important for emerging agricultural biotechnologies whose adoption depends not only on individual perceptions but also on resource availability, extension services, and innovation characteristics.

To address these limitations, this study incorporates Diffusion of Innovations (DOI) theory, which explains how innovation attributes and contextual conditions influence the diffusion of new technologies across farming communities. DOI argues that innovations are adopted when they demonstrate relative advantage, compatibility, manageable complexity, trialability, and observability (Rogers, 2003). These characteristics closely correspond to the multidimensional adoption barriers examined in this study. Economic barriers reduce the perceived relative advantage of the technology; technical barriers increase perceived complexity; knowledge limitations reduce trialability and observability; trust and risk perception affect farmers' confidence in innovation outcomes; and institutional support enhances compatibility through extension services, demonstrations, and policy interventions. Consequently, DOI complements TAM by extending the analysis beyond individual cognition to include the environmental and innovation-specific conditions that shape adoption intention.

Although TAM and DOI explain why farmers may intend to adopt an innovation, they do not explain whether this behavioural intention translates into a willingness to invest financially in the technology. Behavioural acceptance does not necessarily imply economic acceptance, particularly among smallholder farmers who often operate under severe financial constraints. A farmer may recognise the usefulness of rapid portable germplasm identification technology and express a strong intention to adopt it, yet remain unwilling to purchase the technology because of affordability concerns, perceived financial risk, or uncertainty regarding expected returns. Therefore, explaining commercial acceptance requires an economic valuation perspective beyond conventional technology adoption theories.

The Contingent Valuation Method (CVM) addresses this limitation by providing the economic foundation for estimating farmers' willingness to pay for technologies that do not yet have established market prices. CVM captures the monetary value farmers assign to an innovation after evaluating its expected benefits relative to its anticipated costs. Within the proposed framework, willingness to pay represents the final stage of the technology adoption process, reflecting farmers' economic commitment after behavioural acceptance has been established. Thus, CVM extends the explanatory scope of TAM and DOI by linking behavioural intention with economic valuation, enabling assessment of both technology acceptance and commercial feasibility.

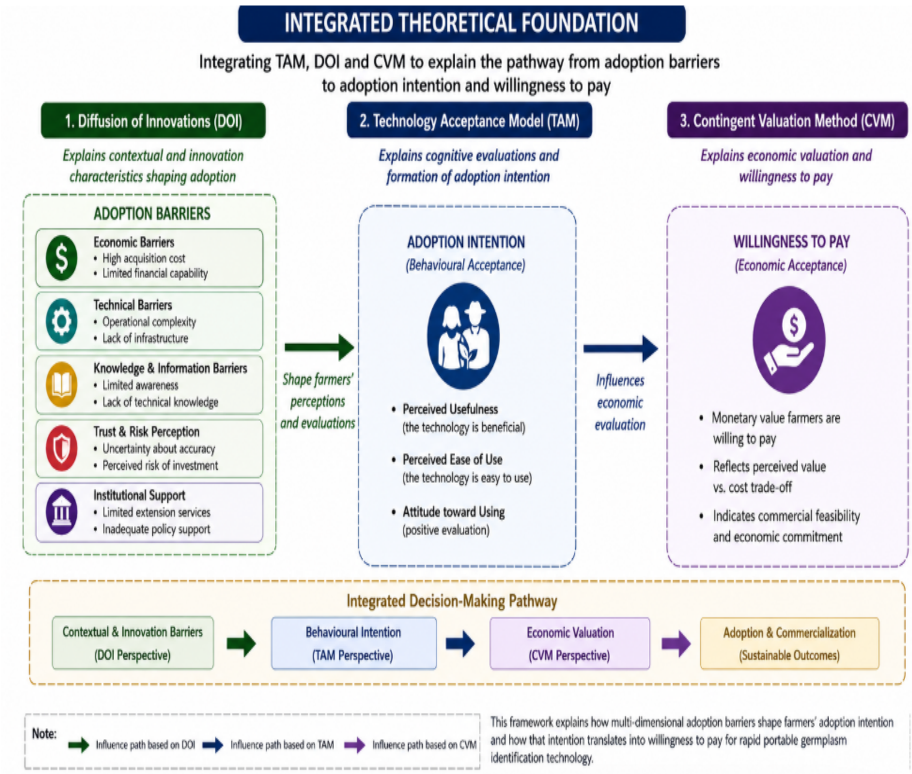

Fig. 1. Theoretical foundation

Accordingly, figure 1 shows the integrated framework proposes a sequential decision-making process. Diffusion-related barriers including economic, technical, informational, trust-related, and institutional factors influence farmers' perceptions of the innovation environment. These contextual conditions shape behavioural intention through the cognitive mechanisms explained by TAM. Behavioural intention subsequently influences willingness to pay, which represents farmers' economic evaluation of the technology within the CVM perspective. By integrating TAM, DOI, and CVM, the proposed framework explains not only why farmers intend to adopt rapid portable germplasm identification technology but also whether they are prepared to invest financial resources in its acquisition. This integration provides a more comprehensive theoretical explanation than any individual theory alone and offers a stronger foundation for understanding both behavioural acceptance and commercialization potential among smallholder farmers in Sichuan.

Economic barriers refer to farmers' perceived financial constraints in acquiring, operating, and maintaining rapid portable germplasm identification technology. For smallholder farmers, adoption decisions are often shaped by limited disposable income, uncertain returns, and sensitivity toward upfront technology costs. Smidt and Jokonya [44] emphasized that small-scale farmers face economic, social, and institutional constraints when adopting digital agricultural technologies. Similarly, Gong *et al*., [19], in their study of farmers in Sichuan Province, found that technology accessibility and economic cognition influence farmers' willingness to adopt digital agricultural production technologies. Therefore, when farmers perceive the technology as costly or financially risky, their intention to adopt is likely to decline.

Building upon the integrated theoretical framework, the proposed hypotheses reflect a sequential causal mechanism linking contextual adoption barriers, behavioural acceptance, and economic valuation. Consistent with the Diffusion of Innovations theory, multidimensional adoption barriers influence farmers' perceptions of the innovation environment. These contextual conditions subsequently shape behavioural intention as explained by the Technology Acceptance Model. Finally, behavioural intention influences willingness to pay through the economic valuation process described by the Contingent Valuation Method. Accordingly, the proposed hypotheses represent an integrated pathway explaining farmers' adoption and commercialization decisions regarding rapid portable germplasm identification technology.

H1: Economic barriers negatively influence adoption intention toward rapid portable germplasm identification technology.

Technical barriers include perceived complexity, operational difficulty, lack of compatibility with existing farming practices, and uncertainty about how the technology functions in field conditions. The Technology Acceptance Model suggests that technologies perceived as difficult to use are less likely to be adopted. Recent agricultural technology studies also show that technical complexity and limited usability reduce farmers' behavioral intention to adopt innovation. Cimino *et al*., [7] found that small farmers' intention to adopt digital platforms depends strongly on perceived usability and compatibility with agricultural activities. Therefore, if portable germplasm identification technology is perceived as complicated or unsuitable for daily farm operations, farmers may hesitate to adopt it.

H2: Technical barriers negatively influence adoption intention toward rapid portable germplasm identification technology.

Knowledge and information barriers refer to limited awareness, insufficient training, and lack of understanding regarding the benefits and operation of the technology. Farmers may not adopt a technology if they do not clearly understand its practical value or how to use it. Gong *et al*., [19] showed that digital agricultural technology services enhance farmers' adoption willingness by expanding information channels, improving operational cognition, and increasing technology accessibility among farmers in Sichuan. Yu *et al*., [51] also found that digital multimedia and information exposure can improve farmers' adoption of agricultural green production technologies. Thus, inadequate knowledge and limited information may weaken farmers' intention to adopt portable germplasm identification technology.

H3: Knowledge and information barriers negatively influence adoption intention toward rapid portable germplasm identification technology.

Trust and risk perception are critical in farmers' evaluation of emerging agricultural technologies. Farmers may question whether the technology produces accurate identification results, whether the device is reliable under field conditions, and whether investment in the technology will generate practical benefits. Yeo *et al*., [50] highlighted that trust, perceived profitability, and confidence in digital agricultural systems strongly shape farmers' technology adoption decisions. In the context of germplasm identification, perceived risk may be even more important because incorrect results may affect seed selection, crop planning, and farm income. Therefore, higher perceived risk and lower trust are expected to reduce adoption intention.

H4: Trust and risk perception significantly influence adoption intention toward rapid portable germplasm identification technology.

Institutional support includes extension services, technical assistance, policy support, subsidies, training, and access to reliable advisory systems. For smallholder farmers, external support is often necessary to reduce uncertainty and improve confidence in adopting new technologies. Zhang *et al*., [54] found that cooperative membership promotes agricultural technology adoption among farmers in Sichuan, suggesting that institutional and organizational support can strengthen innovation uptake. Gong *et al*., [19] similarly confirmed that digital agricultural technology services enhance farmers' willingness to choose digital production technologies in Sichuan. Therefore, stronger institutional support is expected to increase farmers' adoption intention.

H5: Institutional support positively influences adoption intention toward rapid portable germplasm identification technology.

Adoption intention reflects farmers' readiness, motivation, and preference to use the technology. In technology adoption research, intention is commonly treated as a direct predictor of future behavioral action. For rapid portable germplasm identification technology, farmers who perceive the technology as useful, accessible, and valuable are more likely to express willingness to pay for it. Gong *et al*., [19] demonstrated that farmers' willingness to choose digital production technology is influenced by cognitive and accessibility-related factors. Dai *et al*., [10] also found that farmers' intention to use agricultural green production technologies is shaped by perceived usefulness, policy influence, and social networks. Therefore, stronger adoption intention is expected to increase willingness to pay.

H6: Adoption intention positively influences willingness to pay for rapid portable germplasm identification technology.

Farmers who develop stronger behavioural intention toward rapid portable germplasm identification technology are expected to perceive greater economic value from its adoption. Positive behavioural intention reflects confidence in the technology's usefulness, ease of use, and expected benefits, thereby reducing uncertainty associated with financial investment. Consequently, farmers with stronger adoption intention are more likely to demonstrate higher willingness to pay because they anticipate that the benefits derived from the technology outweigh its acquisition and operational costs. Therefore, adoption intention is proposed as the immediate behavioural antecedent of willingness to pay.

The proposed framework conceptualises technology adoption as a sequential behavioural-economic process rather than a collection of independent determinants. Farmers first evaluate contextual barriers associated with rapid portable germplasm identification technology, including affordability, technical complexity, information availability, trust, perceived risk, and institutional support. These contextual evaluations influence behavioural intention, which subsequently determines farmers' willingness to make financial commitments toward technology acquisition. Consequently, willingness to pay is interpreted as the economic consequence of behavioural acceptance rather than an independent behavioural construct. This sequential explanation strengthens the theoretical coherence of the framework by integrating contextual, behavioural, and economic perspectives into a unified technology commercialization process

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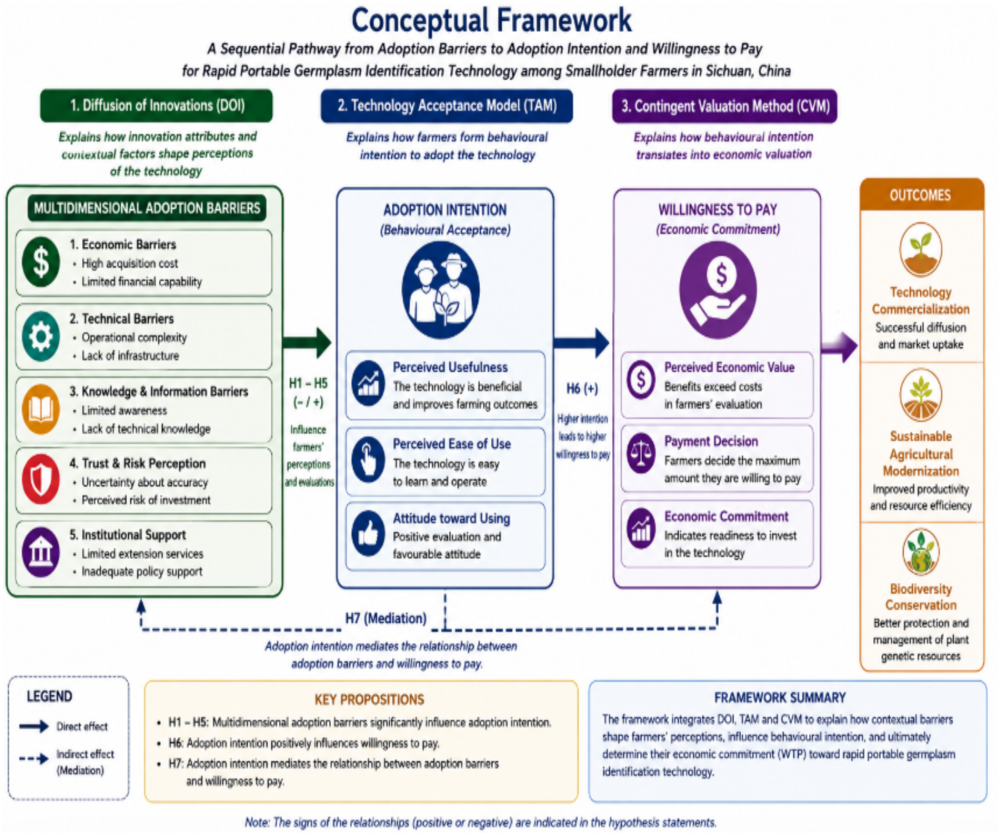

Fig. 2. Conceptual framework

Figure 2 presents the proposed conceptual framework explaining how multidimensional adoption barriers influence smallholder farmers' behavioural and economic responses toward rapid portable germplasm identification technology. The framework conceptualises technology adoption as a sequential decision-making process consisting of three interconnected stages: contextual evaluation, behavioural acceptance, and economic commitment.

The first stage comprises the multidimensional adoption barriers identified through the Diffusion of Innovations (DOI) perspective. These barriers include economic barriers, technical barriers, knowledge and information barriers, trust and risk perception, and institutional support. Rather than acting independently, these contextual factors collectively influence farmers' perceptions regarding the feasibility, compatibility, complexity, and expected benefits of the technology. Consequently, they determine whether farmers develop favourable or unfavourable evaluations toward adopting rapid portable germplasm identification technology.

The second stage represents behavioural acceptance, operationalised as adoption intention and theoretically grounded in the Technology Acceptance Model (TAM). Farmers who perceive fewer barriers, greater institutional support, and stronger technological benefits are expected to develop higher behavioural intention to adopt the technology. Adoption intention therefore functions as the central behavioural mechanism translating contextual conditions into technology acceptance.

The third stage represents economic commitment, measured through willingness to pay and supported by the Contingent Valuation Method (CVM). Following the formation of positive behavioural intention, farmers evaluate whether the anticipated benefits justify the financial investment required for technology acquisition. Willingness to pay therefore represents the economic manifestation of behavioural acceptance, indicating the extent to which farmers are prepared to commit financial resources toward adopting rapid portable germplasm identification technology.

Accordingly, the framework proposes that adoption intention mediates the relationship between multidimensional adoption barriers and willingness to pay. Contextual barriers do not directly determine farmers' willingness to pay; rather, they first influence behavioural acceptance, which subsequently shapes economic valuation. This sequential mechanism provides a comprehensive explanation of how contextual, behavioural, and economic factors interact to determine both technology adoption and commercialization among smallholder farmers in Sichuan.

3. Discussion

The proposed framework suggests that smallholder farmers' willingness to pay for rapid portable germplasm identification technology is not determined by economic affordability alone, but by a wider set of adoption barriers that shape their intention to use the technology. Recent studies show that farmers' adoption of digital and agricultural technologies is commonly influenced by economic constraints, lack of infrastructure, technical knowledge, perceived usefulness, risk-taking, and technology reliability [12]. Similarly, research on small farmers' digital platform adoption confirms that behavioral intention is shaped by perceived performance, effort expectancy, uncertainty, and ecosystem-related factors [7]. In the context of Sichuan, China, this suggests that even if rapid portable germplasm identification technology offers technical advantages, farmers may hesitate to adopt it if the technology is perceived as costly, complex, unfamiliar, unreliable, or weakly supported by extension institutions.

Furthermore, willingness to pay should be understood as an economic outcome of adoption intention. Farmers are more likely to pay for a technology when they perceive clear value, practical usefulness, long-term benefits, and institutional legitimacy. Li et al. (2024), in a study of Chinese farmers, found that farmers' willingness to pay is affected by perceived value, time preference, and the expected future benefits of agricultural land protection. This supports the argument that farmers' payment decisions are shaped by both behavioral and economic reasoning. In addition, portable diagnostic technologies have been recognized for their potential to support rapid, field-based agricultural decision-making, but their wider diffusion depends on cost-effectiveness, usability, validation, standardization, and stakeholder support [49]. Therefore, the present framework positions adoption intention as a key mediating mechanism linking adoption barriers to willingness to pay.

This study contributes to adoption theory by extending technology adoption research into the underexplored context of rapid portable germplasm identification technology among smallholder farmers. While previous studies have examined digital agriculture adoption, mobile extension, and smart farming technologies, limited attention has been given to farmer acceptance of portable germplasm identification tools. By incorporating economic, technical, knowledge-related, trust-based, and institutional barriers, this study broadens the understanding of adoption intention beyond conventional perceived usefulness and ease-of-use factors.

The study also integrates behavioral and valuation perspectives by linking adoption intention with willingness to pay. This integration is important because acceptance of agricultural technology does not automatically imply financial readiness to pay for it. By combining adoption barriers, behavioral intention, and willingness to pay in one framework, the study advances a more complete explanation of how smallholder farmers evaluate emerging agricultural technologies.

For policymakers, the framework highlights the need for subsidy mechanisms, rural training programs, and extension-based demonstrations to reduce adoption barriers. For agri-tech startups, the findings suggest that portable germplasm identification devices should be affordable, simple to operate, and clearly linked to farmers' productivity and income benefits. For seed companies, the technology can support seed authentication, varietal verification, and farmer trust in seed quality. For extension agencies, the framework emphasizes the importance of farmer education, technical assistance, and field demonstrations to increase adoption intention and willingness to pay.

The proposed framework also carries important policy implications for agricultural innovation governance in Sichuan, China. Since rapid portable germplasm identification technology may involve relatively high acquisition costs, technical learning requirements, and uncertainty regarding practical benefits, targeted subsidy schemes could reduce the financial burden faced by smallholder farmers and encourage early-stage adoption. Recent evidence shows that digital extension and agricultural technology services can improve farmers' adoption willingness by expanding access to information, strengthening economic cognition, and improving technological accessibility [19]. Therefore, policy actors such as the Ministry of Agriculture and Rural Affairs and local agricultural bureaus may play an important role in promoting rural technology diffusion through training, demonstration programs, extension services, and financial support mechanisms.

In addition, willingness to pay should not be treated merely as an individual affordability issue, but as a strategic indicator for pricing and commercialization. Studies on farmers' willingness to pay for agricultural technologies suggest that pricing strategies should consider perceived value, payment flexibility, expected productivity benefits, and farmers' income constraints [4,16]. For smallholder farmers, tiered pricing, subsidized pilot access, cooperative-based payment models, and installment schemes may increase acceptance while reducing perceived economic risk. Hatab *et al*., [23] similarly emphasized that flexible payment options and subsidies for low-income farmers can align technology pricing with farmers' economic capacity.

Future research should empirically validate the proposed framework using survey data from smallholder farmers in Sichuan. Empirical testing would allow researchers to examine whether adoption intention mediates the relationship between adoption barriers and willingness to pay. Furthermore, multi-province comparative studies could determine whether the proposed framework is applicable beyond Sichuan, particularly across provinces with different agricultural structures, income levels, digital infrastructure, and extension systems. Finally, longitudinal research is needed to capture how farmers' adoption intention and willingness to pay evolve after exposure to demonstrations, training, subsidies, or repeated use of the technology. This is important because technology adoption is rarely a one-time decision; rather, it develops through learning, trust-building, perceived usefulness, and accumulated experience [53].

4. Conclusions

The proposed conceptual framework advances the literature on agricultural technology adoption by providing several theoretical, contextual, methodological, and practical contributions. Although previous studies have extensively investigated digital agriculture, precision farming, smart agricultural services, and green production technologies, limited attention has been devoted to rapid portable germplasm identification technology, particularly from the perspectives of technology commercialization and farmers' economic decision-making. Consequently, the present study introduces a comprehensive framework that extends existing adoption theories to an emerging agricultural biotechnology with significant implications for biodiversity conservation, seed authentication, and sustainable agricultural modernization.

The first contribution is theoretical. Existing agricultural technology adoption studies typically employ a single theoretical perspective, such as the Technology Acceptance Model (TAM), Diffusion of Innovations (DOI), or other behavioural theories, to explain farmers' adoption decisions. While these theories provide valuable insights into behavioural acceptance, they do not adequately explain whether positive adoption intention subsequently translates into farmers' willingness to make a financial commitment. The present study addresses this limitation by integrating TAM, DOI, and the Contingent Valuation Method (CVM) within a unified framework that simultaneously explains contextual barriers, behavioural acceptance, and economic valuation. This integration extends existing agricultural technology adoption literature by providing a more comprehensive explanation of farmers' technology commercialization decisions.

The second contribution is contextual. Previous studies conducted in China, including those undertaken in Sichuan Province, have primarily examined digital agricultural services, precision agriculture, green production technologies, and digital literacy. In contrast, this study focuses specifically on rapid portable germplasm identification technology, an emerging biotechnology that has received limited scholarly attention despite its strategic importance for crop authentication, plant genetic resource management, and agricultural biodiversity conservation. By concentrating on Sichuan's smallholder farming systems, the framework provides context-specific insights into technology adoption within one of China's most significant agricultural regions.

The third contribution is methodological. Rather than treating adoption intention and willingness to pay as independent outcomes, the proposed framework conceptualizes adoption intention as the behavioural mechanism linking multidimensional adoption barriers with farmers' willingness to pay. This sequential structure captures the transition from behavioural acceptance to economic commitment and therefore provides a more rigorous explanation of technology adoption and commercialization processes than models that examine behavioural intention or willingness to pay separately.

The fourth contribution is practical. Beyond explaining technology adoption behaviour, the proposed framework provides strategic guidance for policymakers, agricultural extension agencies, technology developers, and agribusiness firms seeking to commercialize rapid portable germplasm identification technology. By identifying the multidimensional barriers influencing behavioural acceptance and economic valuation, the framework offers practical recommendations for designing subsidy programmes, extension services, farmer training initiatives, pricing strategies, and commercialization policies that support the successful diffusion of agricultural biotechnology among smallholder farmers.

Collectively, these contributions distinguish the present study from previous agricultural technology adoption research by integrating behavioural and economic perspectives within a single conceptual framework while addressing an emerging agricultural biotechnology that has received limited attention in existing literature.

Recent studies on agricultural technology adoption consistently demonstrate that smallholder farmers' adoption decisions are strongly influenced by economic affordability, technical complexity, institutional support, and perceived usefulness of the technology. Existing empirical evidence further suggests that farmers' willingness to pay (WTP) for emerging agricultural technologies is closely associated with their adoption intention, perceived economic benefits, and trust in the technology system.

For instance, Cimino [7] concluded that small farmers' behavioral intention to adopt digital agricultural platforms is significantly shaped by perceived usefulness, ease of use, and ecosystem support mechanisms. The study emphasized that integrating behavioral and technological dimensions provides a more comprehensive explanation of farmers' adoption intention toward innovative agricultural technologies.

Similarly, Dong *et al*., [13] found that farmers' intention to adopt ecological agricultural technologies in China was positively influenced by subjective perceptions, technology acceptance, and behavioral control. Their findings highlighted that farmers are more likely to adopt agricultural innovations when technologies are perceived as practical, beneficial, and compatible with existing farming activities.

In the context of digital agriculture adoption, Yu *et al*., [51] reported that digital multimedia and information accessibility significantly improve farmers' willingness to adopt agricultural green production technologies. The study further revealed that limited access to information and technological literacy remain major barriers to adoption among rural farming communities.

Recent evidence also indicates that economic and institutional barriers remain critical determinants of technology adoption among smallholder farmers. Pandeya *et al*., [35] concluded that high investment costs, insufficient technical support, and limited financial access significantly hinder the adoption of precision agriculture technologies, particularly among small-scale farmers. Likewise, Kumar et al. (2025) emphasized that credit shortages, inadequate training, and weak market systems continue to constrain agricultural technology adoption in developing agricultural economies.

With regard to willingness to pay, Mastenbroek *et al*., [32] demonstrated that information availability significantly influences smallholder farmers' willingness to pay for certified agricultural technologies. Their findings revealed that farmers are more willing to invest in agricultural innovations when they clearly understand the technology's benefits and expected economic returns. In a more recent study, Mangole *et al*., [30] found that farmers in Tanzania and Burkina Faso showed measurable willingness to pay for mobile agricultural extension applications, although affordability and smartphone accessibility remained substantial constraints.

Furthermore, Feng *et al.,* [16] concluded that policy support, extension services, and perceived usefulness positively influence farmers' willingness to adopt climate-smart agricultural technologies. The study highlighted the importance of government support and institutional facilitation in accelerating agricultural technology diffusion among farming communities.

Collectively, these findings suggest that agricultural technology adoption among smallholder farmers is a multidimensional process involving economic, technological, informational, psychological, and institutional considerations. Although prior studies have extensively explored digital agriculture, precision farming, and climate-smart technologies, limited attention has been given to rapid portable germplasm identification technology, particularly in relation to both adoption barriers and willingness to pay among smallholder farmers in Sichuan. Therefore, this study seeks to address this gap by developing an integrated framework that explains how adoption barriers influence adoption intention and subsequently affect willingness to pay for rapid portable germplasm identification technology.

Acknowledgement

The authors would like to express their sincere appreciation to all individuals and institutions that indirectly contributed to the development of this study. Special gratitude is extended to the agricultural experts, researchers, and academic scholars whose previous studies and insights have provided valuable theoretical and practical foundations for this research. The authors also acknowledge the importance of smallholder farming communities in Sichuan, whose agricultural experiences and challenges continue to inspire research on sustainable agricultural innovation and technology adoption. This research was fully self-funded by the authors, and no external financial support, grant, or sponsorship was received from any public, commercial, or non-profit organization. The authors declare that there are no conflicts of interest regarding the publication of this paper.

Author Contributions Statement

Author 1 was responsible for the conceptualization of the study, literature review, framework development, data interpretation, and manuscript drafting. Author 2 contributed to the theoretical development, methodology design, critical revision of the manuscript, and supervision of the overall research direction. Author 3 assisted in the analysis of agricultural technology adoption literature, refinement of the research framework, and manuscript editing. Author 4 contributed to the discussion on willingness to pay, policy implications, and final manuscript preparation. Corresponding Authors (Author 5 and Author 6), as research supervisors, provided academic supervision, methodological guidance, critical review, and overall validation of the study. All authors have read and approved the final version of the manuscript for publication.

Generative AI Declaration

During the preparation of this work, the authors used ChatGPT (OpenAI) solely to enhance the clarity, grammar, and readability of the manuscript. All generated outputs were critically reviewed, verified, and revised by the authors. The authors accept full responsibility for the accuracy, integrity, and originality of the content presented in this publication.

References

[1] Abebe, Abebaw. "Farmers' willingness to pay for mobile phone-based agricultural extension service in northern Ethiopia." *Cogent Food & Agriculture* 9, no. 1 (2023): 2260605. https://doi.org/10.1080/23311932.2023.2260605.

[2] Ajzen, Icek. "The theory of planned behavior." *Organizational behavior and human decision processes* 50, no. 2 (1991): 179-211. https://doi.org/10.1016/0749-5978(91)90020-T.

[3] Bertoglio, Riccardo, Chiara Corbo, Filippo M. Renga, and Matteo Matteucci. "The digital agricultural revolution: A bibliometric analysis literature review." *Ieee Access* 9 (2021): 134762-134782. https://arxiv.org/abs/2103.12488.

[4] Channa, Hira, Amy Z. Chen, Patricia Pina, Jacob Ricker-Gilbert, and Daniel Stein. "What drives smallholder farmers' willingness to pay for a new farm technology? Evidence from an experimental auction in Kenya." *Food policy* 85 (2019): 64-71. https://doi.org/10.1016/j.foodpol.2019.03.005.

[5] Chowdhury, Mohammad Raziuddin, Md Sakib Ullah Sourav, and Rejwan Bin Sulaiman. "The role of digital agriculture in transforming rural areas into smart villages." (2023). https://arxiv.org/abs/2301.10012.

[6] Choruma, Dennis Junior, Tinashe Lindel Dirwai, Munyaradzi Junia Mutenje, Maysoun Mustafa, Vimbayi Grace Petrova Chimonyo, Inga Jacobs-Mata, and Tafadzwanashe Mabhaudhi. "Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa." *Journal of agriculture and food research* 18 (2024): 101286. https://www.sciencedirect.com/science/article/pii/S2666154324003235.

[7] Cimino, Antonio, Ilda Maria Coniglio, Vincenzo Corvello, Francesco Longo, Juliana Keiko Sagawa, and Vittorio Solina. "Exploring small farmers behavioral intention to adopt digital platforms for sustainable and successful agricultural ecosystems." *Technological Forecasting and Social Change* 204 (2024): 123436. https://doi.org/10.1016/j.techfore.2024.123436.

[8] Chindasombatcharoen, Nopparuj, Naoum Tsolakis, Mukesh Kumar, and Eoin O'Sullivan. "Navigating psychological barriers in agricultural innovation adoption: A multi-stakeholder perspective." *Journal of Cleaner Production* 475 (2024): 143695. https://doi.org/10.1016/j.jclepro.2024.143695.

[9] Cui, Luwen, and Weiwei Wang. "Factors affecting the adoption of digital technology by farmers in China: A systematic literature review." *Sustainability* 15, no. 20 (2023): 14824.

[10] Dai, Qianchun, and Kequn Cheng. "What drives the adoption of agricultural green production technologies? An extension of TAM in agriculture." *Sustainability* 14, no. 21 (2022): 14457. https://doi.org/10.3390/su142114457.

[11] Davis, Fred D. "Perceived usefulness, perceived ease of use, and user acceptance of information technology." *MIS quarterly* (1989): 319-340. https://doi.org/10.2307/249008.

[12] Dibbern, Thais, Luciana Alvim Santos Romani, and Silvia Maria Fonseca Silveira Massruhá. "Main drivers and barriers to the adoption of Digital Agriculture technologies." *Smart Agricultural Technology* 8 (2024): 100459. https://www.sciencedirect.com/science/article/pii/S2772375524000649.

[13] Dong, Hao, Huanyuan Wang, and Jichang Han. "Understanding ecological agricultural technology adoption in China using an integrated technology acceptance model—theory of planned behavior model." *Frontiers in Environmental Science* 10 (2022): 927668. https://doi.org/10.3389/fenvs.2022.927668.

[14] Drupp, Moritz A., Zachary M. Turk, Ben Groom, and Jonas Heckenhahn. "Global evidence on the income elasticity of willingness to pay, relative price changes and public natural capital values. arXiv 2024." *arXiv preprint arXiv:2308.04400*. https://doi.org/10.48550/arXiv.2308.04400.

[15] Eichhorn, Theresa, Jochen Kantelhardt, and Lena Luise Schaller. "Using a Technology Acceptance Model to test factors influencing farmers' intention to perform result-based contract solutions." In *96th Annual Conference, April 4-6, 2022, KU Leuven, Belgium*, no. 321178. Agricultural Economics Society-AES, 2022. https://doi.org/10.22004/ag.econ.321178.

[16] Feng, Xiaoxue, and Suhaiza Zailani. "The antecedents of the willingness to adopt and pay for climate-smart agricultural technology among cooperatives in China." *Sustainability* 17, no. 1 (2024): 19. https://doi.org/10.3390/su17010019.

[17] Geng, Wenxuan, Liping Liu, Junye Zhao, Xiaoru Kang, and Wenliang Wang. "Digital technologies adoption and economic benefits in agriculture: A mixed-methods approach." *Sustainability* 16, no. 11 (2024): 4431. https://www.mdpi.com/2071-1050/16/11/4431.

[18] Gepts, Paul. "Biocultural diversity and crop improvement." *Emerging Topics in Life Sciences* 7, no. 2 (2023): 151-196. https://pmc.ncbi.nlm.nih.gov/articles/PMC10754339/.

[19] Gong, Wei, Ruiyao Ma, and Haixia Zhang. "Digital agricultural technology services and farmers' willingness to choose digital production technology in Sichuan province, China." *Frontiers in Sustainable Food Systems* 8 (2024): 1401316. https://doi.org/10.3389/fsufs.2024.1401316.

[20] Gumbi, Nametshego, Lucas Gumbi, and Hossana Twinomurinzi. "Towards sustainable digital agriculture for smallholder farmers: A systematic literature review." *Sustainability* 15, no. 16 (2023): 12530. https://www.mdpi.com/2071-1050/15/16/12530.

[21] Gyamfi, Emmanuel Kojo, Zag ElSayed, Jess Kropczynski, Mustapha Awinsongya Yakubu, and Nelly Elsayed. "Agricultural 4.0 leveraging on technological solutions: Study for smart farming sector." In *2024 IEEE 3rd international conference on computing and machine intelligence (ICMI)*, pp. 1-9. IEEE, 2024. https://arxiv.org/abs/2401.00814.

[22] Hassim, Omar Abu, Ismah Osman, Asmah Awal, and Fhaisol Mat Amin. "Navigating the path to equitable and sustainable digital agriculture among small farmers in Malaysia: A comprehensive review." *Information Management and Business Review* 16, no. 2 (2024): 173-188. https://ojs.amhinternational.com/index.php/imbr/article/view/3795.

[23] Abu Hatab, Assem, Tabeer Riaz, Mohsin Raza, Raed Abd Elnasser Salama, and Thanh Mai Ha. "A contingent valuation of smallholder farmers' willingness to pay for improved irrigation water supply in Egypt." *Water and environment journal* 39, no. 3 (2025): 275-289. https://doi.org/10.1016/j.agwat.2025.109306.

[24] Hoang, Hung Gia, and Hoa Dang Tran. "Smallholder farmers' perception and adoption of digital agricultural technologies: An empirical evidence from Vietnam." *Outlook on Agriculture* 52, no. 4 (2023): 457-468. https://doi.org/10.1177/00307270231197825.

[25] Hofstetter, Reto, Klaus M. Miller, Harley Krohmer, and Z. John Zhang. "A de-biased direct question approach to measuring consumers' willingness to pay." *International journal of research in marketing* 38, no. 1 (2021): 70-84. https://doi.org/10.48550/arXiv.2005.11318.

[26] Kebede, Hundanol A. "Risk aversion and gender gaps in technology adoption by smallholder farmers: Evidence from Ethiopia." *The Journal of Development Studies* 58, no. 9 (2022): 1668-1692. https://doi.org/10.1080/00220388.2022.2048653.

[27] Li, Hao, Mi Xu, Wei-Yew Chang, and Linhan Feng. "Assessing the impact of farmers' willingness to pay on different cultivated land attribute levels in China: an empirical analysis using the choice experiment method." *Scientific Reports* 14, no. 1 (2024): 23648. https://doi.org/10.1038/s41598-024-74280-0.

[28] Liu, Haoyuan, Zhe Chen, Suyue Wen, Jizhou Zhang, and Xianli Xia. "Impact of digital literacy on farmers' adoption behaviors of green production technologies." *Agriculture* 15, no. 3 (2025): 303. https://doi.org/10.3390/agriculture15030303.

[29] Manzoor, Faiza, Longbao Wei, Mahwish Siraj, Xueqin Lu, and Guo Qiyang. "Digital agriculture technology adoption in low and middle-income countries—a review of contemporary literature." *Frontiers in Sustainable Food Systems* 9 (2025): 1621851. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2025.1621851/full

[30] Mangole, Cool Dady, Kelvin Mulungu, Christian Kamala Kaghoma, Maurice Tschopp, and Menale Kassie. "Smallholder farmers' willingness to pay for the farmbetter mobile app-based agricultural extension: evidence from a BDM experiment in Tanzania and Burkina Faso." *International Journal of Agricultural Sustainability* 24, no. 1 (2026): 2609433. https://www.tandfonline.com/doi/full/10.1080/14735903.2025.2609433.

[31] Hui, M. A. O., and F. U. Yong. "Risk preferences and the low-carbon agricultural technology adoption: evidence from rice production in China." *Journal of Integrative Agriculture* 22, no. 8 (2023): 2577-2590. https://doi.org/10.1016/j.jia.2023.07.002.

[32] Mastenbroek, Astrid, Irma Sirutyte, and Robert Sparrow. "Information barriers to adoption of agricultural technologies: willingness to pay for certified seed of an open pollinated maize variety in Northern Uganda." *Journal of Agricultural Economics* 72, no. 1 (2021): 180-201. https://doi.org/10.1111/1477-9552.12395.

[33] Ohashi, Takumi, Miki Saijo, Kento Suzuki, and Shinsuke Arafuka. "From conservatism to innovation: The sequential and iterative process of smart livestock technology adoption in Japanese small-farm systems." *Technological Forecasting and Social Change* 208 (2024): 123692. https://doi.org/10.48550/arXiv.2307.03338.

[34] Orellana, E., et al. 2025. "Precision Farming: Exploring the Challenges and Opportunities of Digital Agriculture." *Agriculture* 15 (24): 2555. https://www.mdpi.com/2077-0472/15/24/2555.

[35] Pandeya, Shreesha, Buddhi R. Gyawali, and Suraj Upadhaya. "Factors influencing precision agriculture technology adoption among small-scale farmers in Kentucky and their implications for policy and practice." *Agriculture* 15, no. 2 (2025): 177. https://doi.org/10.3390/agriculture15020177.

[36] Thi-Thu-Hong, Phan, Vo Quoc-Trinh, and Nguyen Huu-Du. "A novel method for identifying rice seed purity based on hybrid machine learning algorithms." *arXiv preprint arXiv:2406.07581* (2024). https://arxiv.org/abs/2406.07581.

[37] Prochnow, L., et al. 2025. "Germplasm Conservation and Plant Variety Rights in the Berry Sector." *Genetic Resources and Crop Evolution*. https://link.springer.com/article/10.1007/s10722-025-02553-2.

[38] Olum, Solomon, Xavier Gellynck, Joel Juvinal, Duncan Ongeng, and Hans De Steur. "Farmers' adoption of agricultural innovations: A systematic review on willingness to pay studies." *Outlook on Agriculture* 49, no. 3 (2020): 187-203. https://doi.org/10.1177/0030727019879453.

[39] Rana, Masud, Md Touhidul Islam, Sakhri Abdelwaheb, Hasibul Islam, and SM Shahedul Alam. "Modeling the adoption of financial technology for sustainable agricultural development in Bangladesh using the technology acceptance model." *Discover Sustainability* 6, no. 1 (2025): 1191. https://doi.org/10.1007/s43621-025-02000-3.

[40] Reuters. 2024. "China Seeks to Boost Food Output with Five-Year Smart Farming Plan." October 25, 2024. https://www.reuters.com/markets/asia/china-seeks-boost-food-output-with-five-year-smart-farming-plan-2024-10-25/.

[41] Rufin, Philippe, Pauline Lucie Hammer, Leon-Friedrich Thomas, Sá Nogueira Lisboa, Natasha Ribeiro, Almeida Sitoe, Patrick Hostert, and Patrick Meyfroidt. 2025. "National Level Satellite-Based Crop Field Inventories in Smallholder Landscapes." *arXiv*. https://arxiv.org/abs/2507.10499.

[42] Thi Hoa Sen, Le, Phanith Chou, Flordeliz B. Dacuyan, Ylva Nyberg, and Johanna Wetterlind. "Barriers and enablers of digital extension services' adoption among smallholder farmers: the case of Cambodia, the Philippines and Vietnam." *International Journal of Agricultural Sustainability* 22, no. 1 (2024): 2368351. https://www.tandfonline.com/doi/full/10.1080/14735903.2024.2368351.

[43] Spiegel, Alisa, Wolfgang Britz, and Robert Finger. "Risk, risk aversion, and agricultural technology adoption– A novel valuation method based on real options and inverse stochastic dominance." *Q Open* 1, no. 2 (2021): qoab016. https://doi.org/10.1093/qopen/qoab016.

[44] Smidt, Hermanus Jacobus, and Osden Jokonya. "Factors affecting digital technology adoption by small-scale farmers in agriculture value chains (AVCs) in South Africa." *Information Technology for Development* 28, no. 3 (2022): 558-584. https://doi.org/10.1080/02681102.2021.1975256.

[45] Thomas, Rosemary J., Rebecca Whetton, Andy Doyle, and David Coyle. "Development of a Scale to Measure Technology Acceptance in Smart Agriculture." *arXiv preprint arXiv:2203.15423* (2022). https://doi.org/10.48550/arXiv.2203.15423.

[46] Wambugu, Peterson Weru, Eva Weltzien, Evans Ouma, Desterio Nyamongo, Joseph Kimani Ndungu, Nora Castañeda-Álvarez, Cleophas Nyanjugu, Mathews M. Dida, Vinter Achieng Otiego, and Fred Rattunde. "Enhancing farmers' access and use of conserved germplasm for improved food security and climate resilience: the case of sorghum at Kenya's national genebank." *Plant Genetic Resources* (2026): 1-12.https://www.cambridge.org/core/journals/plant-genetic-resources/article/enhancing-farmers-access-and-use-of-conserved-germplasm-for-improved-food-security-and-climate-resilience-the-case-of-sorghum-at-kenyas-national-genebank/9EA734FC67CB9679473DD95005E55A20

[47] Wang, Wenjun, Hang Ma, Yaodong Qi, Jingxue Ye, Min Lu, and Xueping Wei. "Scientific evolution and translational horizons of plant core germplasm: a global bibliometric synthesis and strategic insights." *Frontiers in Plant*

Science 17 (2026): 1771164. https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2026.1771164/full

[48] World Intellectual Property Organization (WIPO). 2026. "Technology Diffusion in Agriculture." In *World Intellectual Property Report 2026*. Geneva: WIPO.

[49] Yadav, Bishnu, Daurik Lal Pandit, Dhurba Banjade, Dipesh Kumar Mehata, Susmita Bhattarai, Sujan Bhandari, Netra Prasad Ghimire, Puja Yadav, and Prava Paudel. "Insights into the germplasm conservation and utilization: Implications for sustainable agriculture and future crop improvement." *Archives of Agriculture and Environmental Science* 9, no. 1 (2024): 180-193. https://journals.aesacademy.org/index.php/aaes/article/view/09-01-026.

[50] Yeo, M. Lisa, and Catherine M. Keske. "From profitability to trust: Factors shaping digital agriculture adoption." *Frontiers in Sustainable Food Systems* 8 (2024): 1456991. https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2024.1456991/full.

[51] Yu, Xueying, Guojun Sheng, Dongshi Sun, and Rui He. "Effect of digital multimedia on the adoption of agricultural green production technology among farmers in Liaoning Province, China." *Scientific Reports* 14, no. 1 (2024): 13092. https://doi.org/10.1038/s41598-024-64049-w.

[52] Zhang, Xiaoyan, Qing Yang, Abdullah Al Mamun, Mohammad Masukujjaman, and Muhammad Mehedi Masud. "Acceptance of new agricultural technology among small rural farmers." *Humanities and Social Sciences Communications* 11, no. 1 (2024): 1641. https://www.nature.com/articles/s41599-024-04163-2

[53] Zhang, Xiaoyan, Qing Yang, Abdullah Al Mamun, Mohammad Masukujjaman, and Muhammad Mehedi Masud. "Acceptance of new agricultural technology among small rural farmers." *Humanities and Social Sciences Communications* 11, no. 1 (2024): 1641. https://doi.org/10.1057/s41599-024-04163-2

[54] Zhang, Shemei, Zhanli Sun, Wanglin Ma, and Vladislav Valentinov. "The effect of cooperative membership on agricultural technology adoption in Sichuan, China." *China Economic Review* 62 (2020): 101334. https://doi.org/10.1016/j.chieco.2019.101334