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The Role of ICT in Advancing Farmer Welfare: A Systematic Literature Review of Multidimensional Outcomes

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Abstract

Existing studies on the role of Information and Communication Technology (ICT) in agriculture often reduce farmer welfare to economic outcomes, overlooking its social, psychological, and environmental dimensions. This narrow perspective limits a comprehensive understanding of how ICT contributes to rural development. To address this gap, this study systematically reviews peer-reviewed articles published between 2014 and 2024 using the PRISMA protocol. The results map the types of ICT interventions, welfare indicators, and pathways through which ICT influences farmer welfare. The findings show that ICT adoption through mobile communication, digital platforms, and internet-based services enhances not only income and productivity but also social capital, livelihood assets, and subjective well-being. These positive outcomes are more pronounced when ICT adoption is accompanied by extension services, credit access, and capacity-building programs. However, the analysis reveals that infrastructural limitations, digital illiteracy, and financial barriers hinder ICT's full potential, especially among marginalized farmers. The evidence also shows regional imbalances, with research concentrated in a few countries, limiting generalization. By developing a conceptual framework, this review advances a multidimensional understanding of ICT's role in improving farmer welfare. The results provide actionable insights for policymakers and development practitioners to design inclusive and context-sensitive ICT interventions for sustainable rural transformation.

Keywords

Information and communication technology, ICT, farmer welfare, rural development, systematic literature review, digital agriculture, livelihood resilience.

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Introduction

In the paradox of the 21st century, despite humanity's unparalleled agricultural productivity, millions of rural farmers, the essential stewards of global food systems, remain ensnared in cycles of poverty, food insecurity, and social vulnerability. This contradiction represents not just an economic challenge but also a humanitarian disaster that jeopardises the stability of rural communities, the resilience of food systems, and the achievement of global development objectives (Peng et al., 2023; Thanh and Ancev, 2021). The evidence consistently indicates that farmer welfare is not merely an ancillary issue, but rather a fundamental determinant of food security, rural development, and poverty alleviation (Hossain et al., 2024). Alarmingly, smallholder farmers, despite contributing significantly to food production in developing regions, often face fragile livelihoods, inadequate access to markets, and limited policy support, which perpetuate multidimensional poverty and undermine sustainable development (Lopez-Ridaura et al., 2018; Nehring et al., 2017). In the absence of intentional and efficient actions, the global objective of achieving food security

and alleviating rural poverty would remain an elusive goal.

Amidst the enduring rural poverty and food insecurity, the swift and revolutionary incorporation of Information and Communication Technology (ICT) into agriculture presents a positive change with extensive consequences. Farmers are increasingly employing various ICT tools, such as mobile applications, remote sensing, geographic information systems (GIS), big data analytics, and artificial intelligence, to enhance production, lower input costs, and facilitate informed decision-making (El Bilali and Allahyari, 2018). These technologies have transformed conventional farming methods by enabling precision agriculture, facilitating real-time weather forecasts, monitoring soil and crop conditions, and delivering timely market information (Serbulova et al., 2019; Sørensen et al., 2019). Additionally, ICT is crucial to strengthening the connections between farmers, extension services, and research entities, guaranteeing that even the most marginalised farming communities acquire valuable innovations and knowledge (Campo et al., 2017). Furthermore, ICT-enabled value chains enhance input procurement, production efficiency, food traceability, and market access, thereby contributing directly to food security and supply chain resilience (Anam et al., 2025; Wasihun and Maumbe, 2012). In areas constrained by resources and infrastructure, such as Sub-Saharan Africa and certain parts of Asia, the adoption of ICT has shown considerable potential to enhance farmer welfare and foster sustainable development (Maumbe, 2012; Sharma and Bhambri, 2024).

The increasing influence of ICT in transforming agriculture has been significantly propelled by the strategic actions of international organisations, particularly the Food and Agriculture Organisation (FAO) and the World Bank, in the global shift towards digitalisation. These institutions have established digital agriculture, encompassing smart farming, digital extension, and e-agriculture, as a fundamental element of modern rural development strategies (El Bilali et al., 2020; Maumbe, 2012). They have encouraged precision agriculture, remote sensing, big data analytics, and smart greenhouse systems to boost agricultural output and sustainability through comprehensive initiatives and funding (Birner et al., 2021). These programs have expanded market access, reduced intermediary dependency, and strengthened research-extension-farmer links to empower farmers and enhance efficiency. Particularly in developing regions, international agencies have facilitated knowledge transmission and capacity building by collaborating with private sector innovators and local stakeholders to bridge the technological divide. The global attempt to digitally transform agriculture is nevertheless hindered by systemic constraints such as low digital literacy, infrastructure gaps, and expensive technology adoption costs (Finger, 2023).

Although technological advancement presents a great opportunity for enhancing agricultural output, its effectiveness is closely linked to the overarching notion of rural wellbeing, which encompasses more than income generation. Farmers not only react to market incentives but also consistently adjust to social and ecological challenges through diverse livelihood choices, balancing on-farm and off-farm activities based on access to land, education, financial resources, and local opportunities (Caulfield et al., 2021). In several contexts, especially within resource-dependent rural areas, natural resource extraction serves as both a coping mechanism and a livelihood enhancer, mitigating income inequality and contributing to poverty reduction, despite concerns over long-term environmental sustainability (Lopez-Ridaura et al., 2018). In addition to household-level modifications, organised initiatives like social security programs and livelihood diversification have demonstrated the capacity to enhance rural wellbeing comprehensively. Initiatives that facilitate non-agricultural income production have continuously shown substantial effects on poverty reduction and livelihood sustainability, both by increasing incomes and by diminishing households' vulnerability to agricultural disruptions while enhancing food security (Rahut et al., 2018). However, scholars have noted the transient nature of rural livelihoods, where the diversity of income sources fluctuates over time, leading to welfare volatility despite diversification (Dzanku, 2015). The integration of off-farm income into household strategies reshapes farm management practices and livelihood trajectories, further complicating the assessment of welfare beyond income alone (Caulfield et al., 2021). The Sustainable Livelihoods Approach (SLA) offers a pertinent framework, acknowledging welfare as a result of intricate interactions between asset endowments, institutional arrangements, and individual capabilities. It underscores the necessity of tackling vulnerability, resilience, and social equity in rural development (Möllers and Buchenrieder, 2005).

Studies indicate that ICT facilitates farmers' access

to timely and pertinent information regarding markets, weather, pest outbreaks, and agronomic practices, thereby enhancing their decision-making and resource management skills (Aldosari et al., 2019; Anand et al., 2022). Rural women and youth, who frequently cannot access traditional extension programs, benefit greatly from mobile-based advisory services and digital platforms (Jennifer and Enwelu, 2023; Rathnachandra and Malkanthi, 2022). The capacity of ICT to enhance information dissemination and technical support via improved extension systems has been shown to promote the adoption of innovative and climate-smart agricultural practices, essential for managing climate variability and market uncertainties (Gangopadhyay et al., 2019; Ma et al., 2020). Furthermore, empirical studies demonstrate that farmers who actively participate in ICT platforms report enhanced adaptive capacity and livelihood resilience, in addition to increased income (Oyelami et al., 2022; Setu et al., 2022), reinforcing the importance of embedding ICT-driven interventions within rural development and welfare programs.

Despite the promising evidence on ICT's contribution to agricultural productivity and income generation, critical evaluations of existing literature reveal that many studies adopt a fragmented approach, often reducing farmer welfare to economic outputs alone. While several works successfully demonstrate the positive correlation between ICT adoption and increased productivity or income (Oyelami et al., 2022), they frequently neglect the broader welfare dimensions such as social inclusion, psychological well-being, and farmers' perceived quality of life. For instance, Wossen et al. (2017) focus on how access to extension services and cooperative membership enhances household welfare primarily through income effects, yet fall short of analyzing how ICT influences social capital, community engagement, or collective empowerment. Similarly, Zulu et al. (2024) emphasize the economic advantages of credit accessibility and ICT adoption without addressing essential welfare components such as education, healthcare access, or gender equity. Moreover, Kalita and Deka (2024) expose persistent gaps in farmers' knowledge and utilization of ICT, suggesting that limited digital literacy may further constrain the potential of ICT to holistically improve rural welfare. This gap is further highlighted by Chen et al. (2023), who argue that farmers' well-being is also shaped by their environmental quality perceptions and participation in sustainable practices, areas that remain underexplored in the majority of ICT-agriculture studies. Collectively, these critiques underscore the necessity of advancing a more comprehensive framework to assess ICT's influence on rural welfare, incorporating economic, social, and psychological dimensions beyond productivity alone.

While numerous studies have documented the positive influence of ICT on agricultural productivity and income (Aker and Ksoll, 2016; Ma et al., 2020; Oyelami et al., 2022), they frequently neglect critical welfare dimensions such as social inclusion, environmental awareness, psychological well-being, and overall life satisfaction. For example, although Rahman and Huq (2023) illustrate how ICT benefits women's livelihoods, they do not sufficiently capture how these benefits integrate into broader welfare improvements such as empowerment, education, or household resilience. Similarly, variations in regional outcomes, as reflected in Van Campenhout et al. (2020) in Uganda versus Oyelami et al. (2022) in sub-Saharan Africa, highlight inconsistencies in methodological approaches, measurement frameworks, and targeted welfare outcomes. This inconsistency limits the formulation of universally applicable policy recommendations. Furthermore, studies by Kalita and Deka (2024) reveal that even where ICT adoption occurs, its influence on environmental quality perceptions, social cohesion, and quality of life remains underexplored. The scattered nature of these findings calls for a systematic review that not only aggregates existing evidence but also critically evaluates how ICT shapes farmer welfare beyond economic returns.

Against this backdrop, this study aims to systematically consolidate and critically analyze the existing body of literature by addressing three core research questions. First, what indicators of farmer welfare have been employed in ICT-related research? Second, what types of ICT interventions have been documented across the existing studies? Third, how does ICT influence farmers' welfare in its multiple dimensions? To answer these questions, this review is designed with five specific objectives. First, it seeks to assess the extent to which the application of ICTs affects farmers' welfare across different contexts. Second, the study aims to identify the most widely adopted welfare indicators used to measure farmer welfare within ICT-related studies. Third, it will explore which dimensions of farmer welfare, economic, social, psychological, and environmental, are

most influenced by ICT interventions. Fourth, this review intends to map the various pathways through which ICT adoption contributes to improving farmer welfare, identifying both direct and indirect mechanisms. Lastly, the study aims to uncover the driving and inhibiting factors that shape the adoption and effectiveness of ICTs in enhancing farmer welfare, thus offering valuable insights for policy-makers, development agencies, and future research. This systematic review offers several important contributions to the existing body of knowledge on ICT and farmer welfare. First, it provides a comprehensive synthesis of fragmented and often isolated studies by systematically mapping the diverse indicators, interventions, and pathways through which ICT influences farmer welfare. While prior research has largely focused on productivity and income effects, this review broadens the lens by incorporating a multidimensional welfare perspective, encompassing social, psychological, and environmental aspects that have often been overlooked. Second, by identifying the most frequently used welfare indicators and categorizing ICT interventions documented in the literature, this study establishes a structured foundation for future empirical research and policy development. Third, this review contributes by uncovering the enabling and constraining factors that shape the success or failure of ICT interventions in enhancing farmer welfare, offering insights into the mechanisms that either amplify or limit ICT's potential. Finally, the review generates a conceptual framework that links ICT adoption pathways with farmer welfare outcomes, bridging theoretical gaps and providing actionable insights for development practitioners, policymakers, and scholars aiming to design more effective ICT-based interventions for rural development.

The remainder of this article is organized as follows. The next section presents the methodology employed to conduct the systematic literature review, including the review protocol, search strategy, selection criteria, and analytical approach. This is followed by the results section, which systematically reports the findings related to the types of ICT interventions identified, the various farmer welfare indicators used, and the pathways through which ICT influences welfare outcomes. Subsequently, the discussion section interprets the findings by linking them to existing theories and empirical evidence, highlighting implications for policy, practice, and future research. The article concludes by summarizing the key insights, addressing limitations, and proposing directions for advancing research on the relationship between ICT and farmer welfare.

Materials and methods

This study systematically followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 protocol to ensure transparency, comprehensiveness, and methodological rigor (Page et al., 2021). The protocol provided a structured framework for identifying, screening, and selecting relevant studies while minimizing potential biases throughout the review process. By adhering to the updated guidelines, this study ensured the credibility and replicability of the systematic review, facilitating a robust synthesis of existing evidence on the relationship between ICT adoption and farmer welfare.

Eligibility criteria

In conducting this review, explicit inclusion and exclusion criteria (Table 1) were rigorously established to ensure methodological precision and scholarly relevance. Literature published within the period from 2014 to 2024 was included to maintain contemporary relevance and capture recent advancements in the field. Articles published outside this timeframe were systematically excluded

Inclusion	Exclusion
Published in 2014 to 2024 Written in English Research article The topic is the effect of ICT on farmer welfare Peer-reviewed article Studies in agriculture The samples are farmers	Out of 2014 to 2024 Non-English Book chapter, review article, short communication, proceeding, dissertation or thesis Methodological comparison Topics outside agriculture No ICT intervention or welfare indicator Only discuss the technical aspects of ICT Only use one variable of ICT or farmer welfare The samples are not farmers or farming households

Source: Authors' own elaboration based on the eligibility criteria of this systematic literature review.

Table 1: The inclusion and exclusion criteria.

to limit potential historical bias and outdated information. English was selected as the exclusive language for included articles to facilitate clear analysis and international scholarly communication. Consequently, non-English language publications were excluded from consideration. The review was limited strictly to peer-reviewed research articles to guarantee methodological robustness and credibility, while publications such as book chapters, review articles, short communications, conference proceedings, dissertations, and theses were systematically excluded to maintain scientific rigour. The central thematic criterion for inclusion was the explicit investigation into the effect of ICT on farmer welfare. Therefore, studies outside the agricultural sector or those that solely discussed technical aspects of ICT without linking to farmer welfare were excluded. Additionally, articles that did not explicitly address ICT interventions or failed to provide measurable welfare indicators were excluded to ensure the review's focus remained precise and analytically useful. Included studies were required to have clearly defined samples consisting specifically of farmers or farming households. Articles with samples outside of this demographic were excluded to maintain homogeneity and relevance to the research objectives. Furthermore, studies employing only a single variable related to either ICT or farmer welfare, as well as methodological comparison studies without direct relevance to welfare outcomes, were excluded to ensure a comprehensive analysis of the interrelationship between ICT interventions and farmer welfare.

Source and search strategy

This review utilised a structured search methodology to identify relevant scholarly articles indexed in Scopus and Web of Science (WoS). Those databases were chosen for their extensive inclusion of peer-reviewed academic journals spanning multiple disciplines, ensuring rigorous and high-quality source material. The search strategy incorporated a carefully constructed combination of keywords specifically aimed at encapsulating the central research theme, namely the interplay between ICT and farmer welfare. The primary search string employed was as follows:

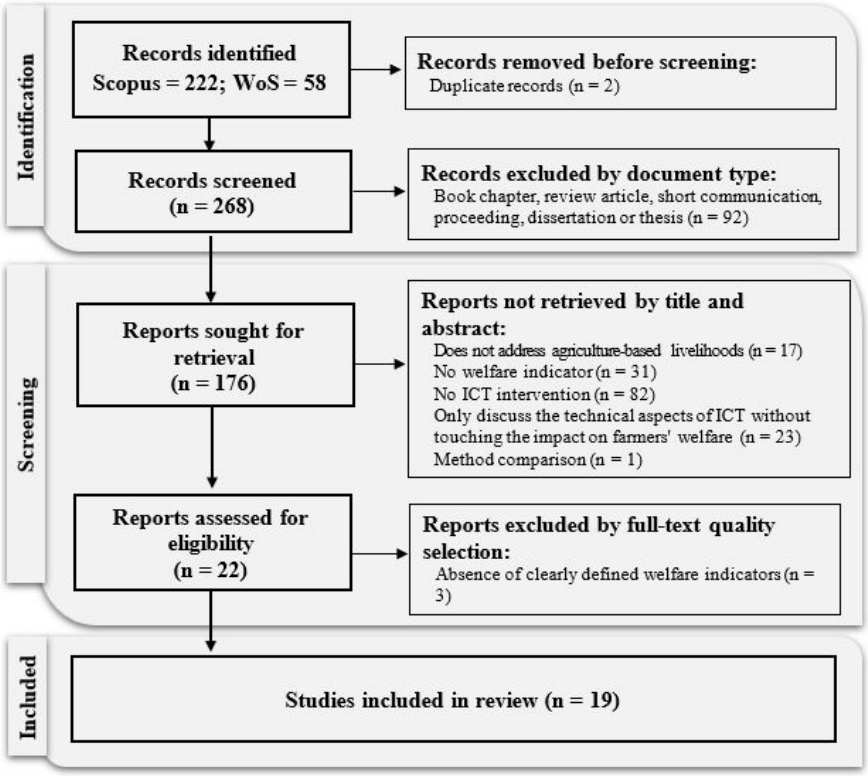
TITLE-ABS-KEY (("ICT" OR "information and communication technology") AND ("farmer" OR "smallholder") AND ("welfare" OR "well-being" OR "livelihood" OR "income" OR "prosperity"))

The abbreviation "ICT" was complemented by its expanded form, "information and communication technology," to ensure comprehensive coverage of the existing literature. Similarly, the keyword "farmer" was augmented with "smallholder" to include literature relevant to small-scale agricultural contexts. Additionally, the concept of welfare was broadly represented through multiple synonymous terms: "welfare," "well-being," "livelihood," "income," and "prosperity," thus capturing diverse terminological variations employed within agricultural economics, rural development, and socioeconomic research.

Selection process

The selection process for identifying eligible studies was conducted systematically and rigorously. Initially, all identified records from the database were imported into bibliographic management software to eliminate duplicate records. Subsequently, the remaining records underwent a two-stage screening process. In the first stage, titles and abstracts were independently screened against the pre-defined inclusion and exclusion criteria. Discrepancies in screening outcomes were resolved through consensus-based discussions, with unresolved cases adjudicated by an additional evaluation. In the second stage, full texts of potentially eligible articles were retrieved for detailed assessment, again employing the established inclusion and exclusion criteria. Each full-text article was independently evaluated to confirm eligibility. Any disagreements were resolved through further discussions to reach consensus or, if necessary, by consulting an additional evaluator. Throughout this systematic selection process, automation tools were not utilized; all screenings were manually performed to ensure methodological precision and consistency in decision-making. Figure 1 illustrates the detailed article selection flow used to finalize studies included in this systematic literature review.

The article selection process commenced with an initial identification of 270 records from the database. Duplicate records (n = 2) were subsequently eliminated, resulting in 268 unique records eligible for screening. During the initial screening phase, records were assessed based on document type. A total of 92 records were excluded as they comprised book chapters, review articles, short communications, conference proceedings, dissertations, or theses, leaving 176 records for further review. In the subsequent retrieval stage, the titles and abstracts of these 176 records were evaluated in detail against specific thematic and methodological criteria. As a result, 17 records were excluded for addressing



Source: Authors' own elaboration based on the PRISMA 2020 protocol and the study selection process.

Figure 1: Article eligibility screening flow diagram (PRISMA protocol).

non-agricultural sectors, 31 lacked explicit welfare indicators, 82 did not include ICT interventions, 23 discussed only technical aspects of ICT without analyzing impacts on farmers' welfare, and one study was excluded for methodological comparison without direct relevance to welfare outcomes. Thus, 22 articles proceeded to full-text evaluation. During the final full-text evaluation, three additional articles were excluded due to the absence of clear welfare indicators. Ultimately, 19 studies met all inclusion criteria and were included in this review.

Data collection process

Data from the included reports were systematically extracted using an artificial intelligence-based tool (GPT-4o). This extraction process leveraged advanced Natural Language Processing (NLP) capabilities, enabling efficient identification and synthesis of relevant information. The tool was prompted to accurately extract specific data points, including year of publication, article title, keywords, country of study, journal name, sample size, respondent type, data type, data source, data analysis technique, welfare indicators, types of ICT interventions, and the reported effects of ICT interventions on farmer welfare. Following the automated extraction, all synthesized data were independently reviewed to ensure accuracy, completeness, and consistency. Any discrepancies or uncertainties identified during the review were carefully re-examined and clarified, thereby reinforcing the reliability and validity of the extracted information.

Data items

Outcomes sought for data extraction included clearly defined welfare indicators (such as income, food security, social capital, livelihood assets, subjective well-being, and bargaining power), with explicit effects of ICT interventions. All compatible results related to these outcomes, including various measures, time points, and analytical methods, were systematically collected to ensure a comprehensive assessment of the impact of ICT on farmer welfare. Moreover, other variables systematically collected included the year of publication, title, keywords, country of study, journal, sample size, respondent characteristics, type of data (primary or secondary), data source (e.g., surveys, randomized controlled trials, panel data), analytical techniques (e.g., econometric analysis, qualitative analysis), and types of ICT interventions used. Assumptions regarding missing or unclear information were minimized through careful re-examination of each included report. When certain information

remained unclear or incomplete, assumptions were explicitly documented based on contextual details provided in the studies.

Study risk of bias assessment

Risk of bias assessment for each included study was systematically conducted using a customized quality assessment checklist specifically designed for this systematic literature review. The checklist comprised three criteria: clarity of objectives and research questions, relevance and appropriateness of research methodology, and clarity of data related to the measurement of farmers' welfare. The researcher independently evaluated each study according to these criteria. Areas where information was unclear or incomplete were explicitly documented to transparently communicate potential biases and limitations within the included studies.

Effect measures

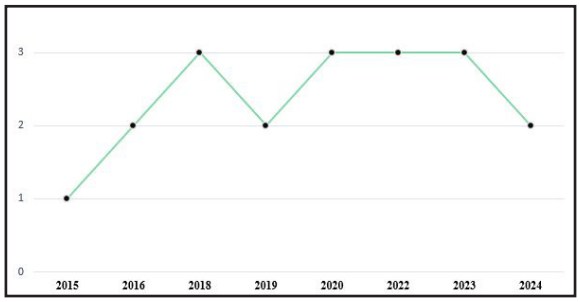
For each welfare outcome, specific effect measures were employed to synthesize and present results. Income-related outcomes used percentage increases, mean differences, and absolute income gains. Food security measures included changes in food availability, dietary diversity scores, and reductions in food insecurity rates. Social capital outcomes involved assessments of changes in network size and qualitative evaluations of community engagement. Livelihood assets outcomes measured both quantitative and qualitative changes in resources such as land, livestock, and savings. Subjective well-being and bargaining power outcomes were primarily assessed through qualitative evaluations or ordinal scales indicating improvement levels.

Synthesis methods

Studies were included in the synthesis based on explicit alignment with the predefined inclusion criteria, particularly relevance to ICT interventions and measurable farmer welfare outcomes. Intervention characteristics were tabulated and systematically compared to ensure accurate grouping and synthesis of results. Data preparation involved converting and harmonizing diverse measurement units through careful estimation when data were unavailable. Results were systematically tabulated to facilitate clear visual presentation through tables, a Sankey diagram, a Venn diagram, a word cloud, and descriptive summaries. A narrative synthesis approach was employed due to methodological diversity and heterogeneity of outcomes among the included studies. This method allowed for comprehensive integration and detailed explanation of findings. Possible causes of heterogeneity among study results were explored through comparative analysis of factors such as regional differences, variations in ICT types, and methodological approaches.

Results and discussion

Following the PRISMA 2020 protocol, this review synthesises 19 carefully selected studies to show how ICT adoption affects farmer welfare. The findings demonstrate both the diversity of ICT interventions employed in various agricultural settings and the numerous ways these technologies influence farmers' welfare. This section systematically reports studies by geography, intervention type, welfare indicators, and analytical methods to provide an integrated understanding of both direct and indirect pathways linking ICT adoption to farmer welfare improvements in economic, social, and psychological areas.

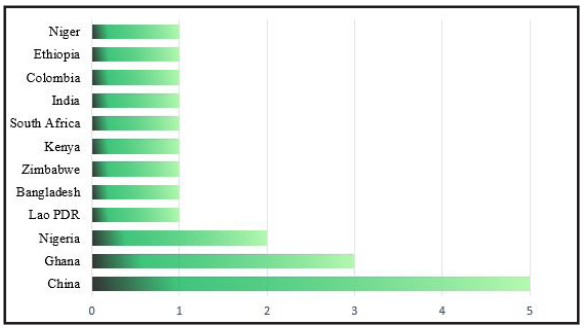


Source: Authors' own elaboration based on the systematic literature review results.

Figure 2: Number of articles evaluating the impact of ICT on farmer welfare by year for 2015 to 2024.

Figure 2 presents the trend in the number of publications discussing the effect of ICT on farmer welfare. Over the ten-year period from 2015 through 2024, the annual number of research article publications exhibited a modest but discernible upward trajectory punctuated by minor fluctuations. Beginning with a single article in 2015, output doubled to two in 2016 and reached a peak of three publications in 2018. A slight dip occurred in 2019 before rebounding to three articles in 2020. Although data for 2017 and 2021 are absent, potentially reflecting gaps in data collection rather than zero output during the period, the number of publications from 2022 to 2023 remained steady at three articles per year. In 2024, there was a marginal decline to two articles, suggesting a possible transient ebb in productivity rather than a definitive downturn.

The distribution of research articles by country reveals a pronounced concentration of scholarly output within a small subset of nations (Figure 3).

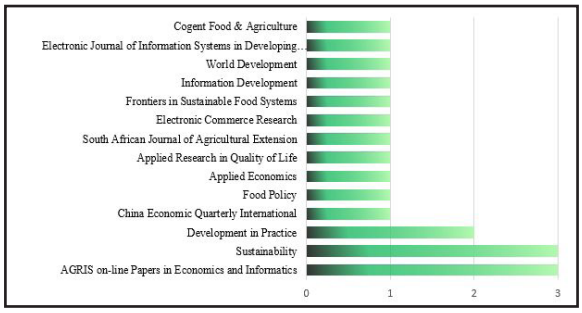


Source: Authors' own elaboration based on the systematic literature review results.

Figure 3: Number of articles evaluating the impact of ICT on farmer welfare by countries for 2015 to 2024.

China emerges as the predominant contributor, accounting for five publications, surpassing Ghana's three articles by 67% and doubling Nigeria's output. In contrast, nine countries (Lao PDR, Bangladesh, Zimbabwe, Kenya, South Africa, India, Colombia, Ethiopia, and Niger) each contributed a single article, collectively representing only 30% of the total corpus. This marked asymmetry indicates a skewed geographic distribution of research activity, suggestive of disparities in research infrastructure, funding allocation, and institutional capacity. Scientifically, such heterogeneity may introduce bias in the global evidence base, potentially limiting the generalizability of findings and underscoring the need for targeted capacity building initiatives in underrepresented regions.

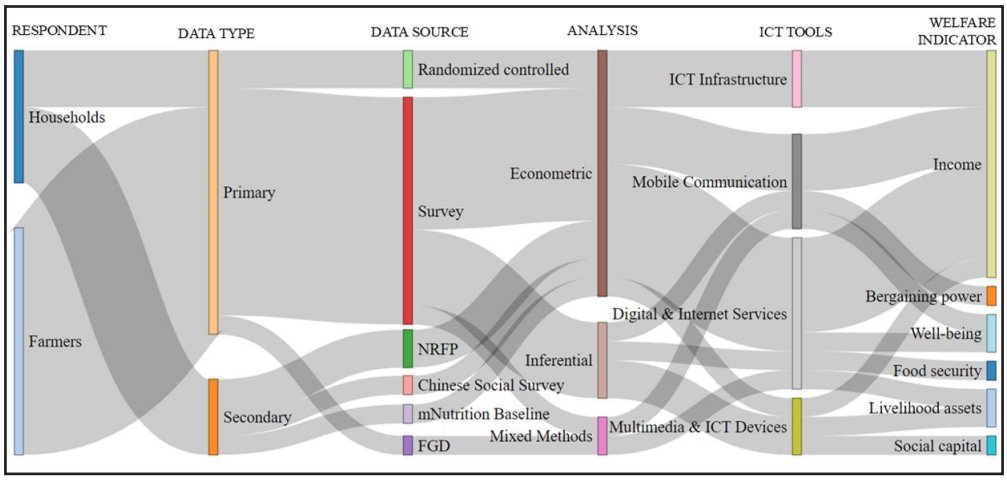
Figure 4 shows the distribution of articles across academic journals. The observed concentration of publications within AGRIS on-line Papers in Economics and Informatics and Sustainability suggests these outlets occupy central roles in disseminating research on the topic, potentially reflecting their editorial focus and perceived relevance to the field. The presence of Development in Practice as a secondary contributor indicates a modest breadth of engagement beyond the primary journals. Meanwhile, the dispersion of single articles across fourteen diverse journals signals an interdisciplinary research landscape, wherein scholarship intersects with domains ranging from agricultural economics and food policy to information systems and sustainable development. Collectively, these patterns indicate both a core set of journals that serve as focal dissemination channels and a wider periphery that accommodates specialized or cross-disciplinary contributions.



Source: Authors' own elaboration based on the systematic literature review results.

Figure 4: Number of articles evaluating the impact of ICT on farmer welfare by journal for 2015 to 2024.

The Sankey diagram and accompanying tabular data together illustrate the pathways through which distinct respondent groups, data types, sources, analytical methods, ICT modalities, and welfare indicators interrelate in the assembled body of research (Figure 5). Specifically, households and

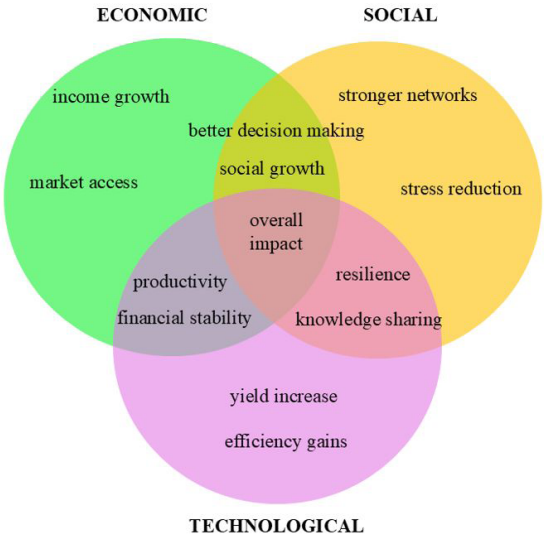


Source: Authors' own elaboration based on the systematic literature review results.

Figure 5: Sankey diagram flow of the sample, data type, data source, and welfare indicators connections.

farmers constitute the two principal respondent cohorts. Moreover, primary data predominate whereas secondary data are drawn from established panel instruments (National Rural Fixed-Point Survey, Chinese Social Survey, and mNutrition baseline), with randomized controlled trial datasets featuring in two instances. Methodologically, causal econometric analysis emerges as the dominant analytic framework, followed by descriptive-inferential procedures and, to a lesser extent, qualitative mixed-methods inquiry. In terms of ICT modalities, digital and Internet services represent the most extensively investigated intervention, channelled from both primary surveys and secondary sources into predominantly econometric analyses that principally quantify effects on household income. Mobile communication constitutes the second most frequently studied technology; causal econometric designs based on randomized trials and survey data link this modality primarily to income enhancement, with secondary associations to subjective well-being and bargaining power. Multimedia and ICT devices are examined exclusively through primary survey and mixed-methods approaches, yielding empirical linkages to social capital accumulation and the augmentation of livelihood assets. ICT infrastructure appears in two secondary-data econometric studies, both of which focus on its impact on income. Collectively, the flows depicted in the diagram underscore the predominance of causal econometric evidence for digital and mobile technologies vis-à-vis income outcomes, whereas non-income welfare dimensions are explored chiefly through descriptive and qualitative methodologies. Furthermore, it is highlighted that the strongest empirical evidence base resides in causal econometric studies of digital/internet services and mobile communication on income outcomes, whereas qualitative and descriptive work informs non-income indicators (social capital, food security, livelihood assets). The diversity of data sources and analytic approaches underscores the multidisciplinary nature of ICT-welfare research and the varying degrees of methodological rigor applied across different ICT modalities and welfare dimensions.

Figure 6 depicts a framework that traces the effects of ICT adoption on various dimensions of farmer welfare. Adopting information and communication technologies generates a cascade of positive effects on farmer welfare by directly enhancing access to critical resources and market opportunities. When farmers invest in ICT infrastructure, they obtain timely access to market information and agronomic knowledge, which boosts productivity and increases income. Furthermore, leveraging digital and internet services enables farmers to exchange data in real time, participate in online markets, and make evidence-based decisions.



Source: Authors' own elaboration based on the systematic literature review results.

Figure 6: The dimension of the effect of ICT adoption on farmers' welfare.

These capabilities not only elevate household income but also improve food security, foster the accumulation of livelihood assets, and strengthen social capital through enhanced information sharing and collaboration. Moreover, mobile communication significantly enhances connectivity among farmers, buyers, and extension agents, thereby improving transaction efficiency and elevating farmers' bargaining power in local and regional markets. In addition, the use of multimedia and ICT devices facilitates skills acquisition and peer-to-peer knowledge transfer, which expands social networks, augments livelihood asset portfolios, and raises subjective well-being. Across all ICT modalities, income enhancement emerges as the most immediate and measurable outcome, while broader non-monetary benefits, such as improved food security, greater social capital, and enhanced livelihood resilience, arise primarily from digital services and multimedia applications.

The reviewed studies demonstrate a consistent positive association between various ICT interventions and improvements in farmer welfare across diverse geographic contexts (Table 2). In China, multiple studies highlight

Author(s)	Country	ICT Intervention	How ICT Affects Farmer Welfare
Zhu et al. (2022)	China	Village-level coverage (2G/3G, internet)	Promotes income growth; initial inequality, reduces disparity long-term.
Aker and Ksoll (2016)	Nigeria	Basic mobile usage	Diversification to cash crops; long-term resilience benefits.
Bounkham et al. (2022)	Laos	Smartphone apps	Higher yield, profit via real-time info and extension services.
Shaibu et al. (2018)	Ghana	Mobile phone, digital TV, PC	Better social ties, efficiency, income via fast communication.
Zhu et al. (2024)	China	Village-level internet, 3G	Raises labor productivity, income; shifts labor off farm.
Zhu et al. (2020)	China	Smartphones, computers, basic internet	Higher income, improved mental well-being.
Oparinde (2023)	Nigeria	Mobile and internet (price/info access)	Increased agroforestry adoption, income, and food security.
Guo et al. (2018)	China	Distance e-learning (web-based)	Raises productivity, input use intensity, income in intensive-use areas.
Rahman and Huq (2023)	Bangladesh	Smartphones, apps, call centers, SMS alerts	Boosts knowledge, resilience; empowers women; reduces crop losses.
Masuka et al. (2016)	Zimbabwe	Mobile phones (calls, SMS, money)	Improved market info, decision-making; reduced costs.
Okello et al. (2020)	Kenya	Mobile-based market information system (MIS)	Enhances market participation, income, input use.
Ma et al. (2020)	China	Smartphones (internet, social, calls)	Higher farm/off-farm income; gender differences noted.
Zulu et al. (2024)	South Africa	Mobile, radio, TV, internet channels	ICT + credit significantly increases income.
Sarkar et al. (2022)	India	Radio, TV, phone, apps, website, IVR	Enhances all livelihood capitals; improves income and resources.
Siaw et al. (2020)	Ghana	Broad internet usage	Internet use boosts farm (20%) household (15%) incomes.
Anadozie et al. (2021)	Nigeria	Mobile phones	Stronger networks, enhanced income levels and resilience.
Camacho and Conover (2019)	Colombia	Mobile SMS	Slightly better info access; potential long-term welfare gains.
Tirkaso and Hess (2015)	Ethiopia	General ICT	Positive income gains linked to ICT spending.
Abubakari et al. (2023)	Ghana	Mobile phones	Mobile phones raise crop income (7%); strengthen market links.

Source: Authors' synthesis based on the reviewed studies

Table 2: ICT Use and Impact on farmer welfare by study.

the transformative effect of village-level coverage, internet services, and smartphone applications in increasing income, productivity, and psychological well-being (Zhu et al., 2022; Zhu et al., 2024; Zhu et al., 2020; Ma et al., 2020; Guo et al., 2018). These interventions have also contributed to structural shifts in labour allocation, moving workers from on-farm to off-farm sectors, while gradually narrowing income disparities among farmers. In Sub-Saharan Africa, particularly in Nigeria and Ghana, basic mobile usage and more advanced tools such as mobile phones, SMS, and internet-based platforms have also shown promising results. In Nigeria, Aker and Ksoll (2016) found that basic mobile access encouraged diversification into marginal cash crops, with potential long-term benefits. Similarly, more complex ICT usage in the form of market information systems and agroforestry applications enhanced income levels and resilience (Oparinde, 2023; Anadozie et al., 2021). In Ghana, ICTs such as mobile phones, digital TV, and internet connectivity supported improved communication, decision-making, and market participation, resulting in higher incomes and social capital (Shaibu et al., 2018; Abubakari et al., 2023; Siaw et al., 2020).

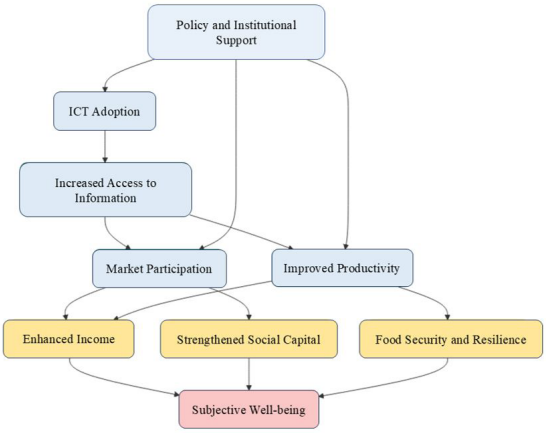
Across South and Southeast Asia, ICT applications also contributed to positive welfare outcomes.

In Bangladesh, the integration of smartphones, apps, call centres, and SMS alerts improved knowledge dissemination, boosted resilience, and empowered women. In India, a comprehensive ICT ecosystem comprising radio, television, mobile apps, and IVR channels contributed to improvements in all five livelihood capitals (Sarkar et al., 2022). Likewise, in Laos, smartphone-based interventions enabled farmers to access real-time information and extension services, which in turn led to increased yields and profits (Bounkham et al., 2022).

In East and Southern Africa, ICTs such as mobile-based market information systems in Kenya and integrated media channels in South Africa were associated with enhanced income and market engagement (Okello et al., 2020; Zulu et al., 2024). In Zimbabwe, mobile phones equipped with financial and informational functions supported decision-making and reduced transaction costs (Masuka et al., 2016). Similarly, in Ethiopia, general ICT investments correlated positively with income gains, especially among wheat producers.

In Latin America, evidence from Colombia indicates that while SMS-based information services improved farmers' engagement with ICTs, short-term welfare outcomes remained limited, with potential for delayed benefits (Camacho and Conover, 2019). This pattern suggests that the effectiveness of ICTs may depend not only on the technology itself but also on user adaptation and the institutional environment. Across these studies, smartphone applications, integrated communication platforms, and internet connectivity appear to yield more substantial impacts on productivity and income compared to basic mobile usage. Moreover, where ICT is combined with institutional support (e.g., credit access or extension services), the synergistic effects tend to be more pronounced, particularly in terms of resilience, social capital, and long-term welfare gains.

The conceptual framework (Figure 7) illustrates the pathways through which ICT adoption influences farmers' welfare. Policy and institutional support serve as a foundational enabler, fostering an environment conducive to ICT adoption through infrastructure development, extension services, and capacity-building initiatives. Once adopted, ICT enhances farmers' access to timely and relevant information, which in turn improves market participation and agricultural productivity. These improvements generate both direct and indirect welfare outcomes. Economically, increased income emerges as the most immediate and measurable benefit. Socially, ICT facilitates the strengthening of social capital by fostering peer-to-peer communication and collective learning, while also improving food security and resilience through better-informed farm management and risk mitigation.

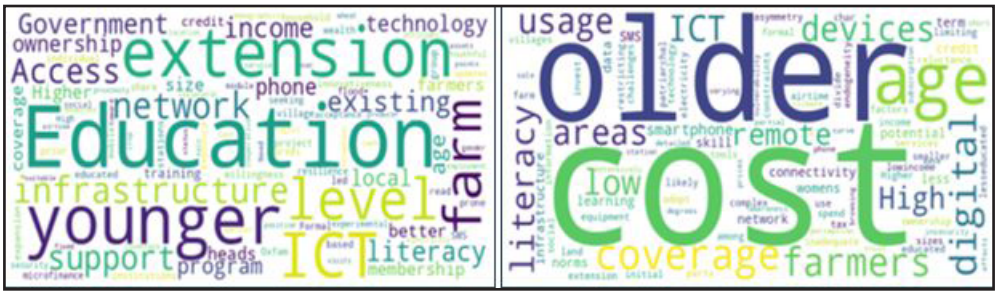


Source: Authors' own elaboration based on the systematic literature review results.

Figure 7: ICT adoption pathways and farmer welfare outcomes.

Ultimately, the combination of economic and social gains leads to enhanced subjective well-being, highlighting that the impacts of ICT extend beyond financial metrics to encompass farmers' overall quality of life. This framework also emphasizes that the effectiveness of ICT adoption is contingent upon the presence of complementary institutional supports, without which welfare outcomes may remain limited or unevenly distributed.

The synthesis of existing literature identifies education and literacy as the most frequently cited driving factors influencing farmers' adoption of ICT , while financial constraints and high technology costs emerge as the main inhibiting factors (Figure 8A and 8B). Studies consistently highlight formal education, digital literacy, and younger age demographics as critical determinants facilitating ICT adoption among farming communities. Additionally, prior exposure to technology and innovativeness significantly contribute to farmers' willingness and capacity to integrate ICT solutions effectively. Moreover, Government initiatives and infrastructure also prominently appear in multiple analyses, particularly emphasizing government-led ICT infrastructure projects, local institutional supports, and comprehensive extension services that collectively enhance ICT adoption rates. Similarly,



Source: Authors' own elaboration based on the systematic literature review results.

Figure 8: Driving (A) and inhibiting (B) factors to ICT adoption.

access to technological resources, including experimental mobile platforms, widespread mobile network coverage, and the provision of specific training programs, emerge as influential in driving technology uptake among farmers. Furthermore, demographic and social factors, notably youthfulness and proximity to ICT service points, are significant predictors of ICT adoption. The younger farming demographic demonstrates greater adaptability and positive attitudes toward new technologies, reflecting an enhanced likelihood of ICT usage. Economic variables, such as income level, cost considerations related to airtime and electricity, and the economic nature of the crops cultivated, have been recognized as vital components influencing farmers' ability to adopt ICT. Finally, financial and institutional supports, including access to credit, cooperative memberships, extension visitation frequency, and the availability of collateral resources, significantly contribute to increased ICT adoption among agricultural communities. Collectively, these factors indicate a multifaceted landscape wherein education, government infrastructure, demographic characteristics, technological accessibility, economic capacity, and institutional support systems interplay critically to shape farmers' decisions regarding ICT adoption.

On the other hand, the reviewed literature highlights financial constraints and the high cost of technology as predominant inhibitors in the adoption of ICT (Figure 8B). Notably, the high initial costs associated with purchasing smartphones, ICT equipment, and ongoing connectivity expenditures significantly deter adoption among low-income and less-educated agricultural communities. Multiple studies underline the pronounced financial barriers, particularly among older farmers and those experiencing income constraints, emphasizing the adverse impact of economic limitations on technology adoption. Moreover, infrastructure and network-related issues are similarly recurrent inhibitors identified across various studies. Limited or inadequate network coverage, especially prevalent in rural and remote regions, restricts farmers' access and reduces the practical applicability of ICT services. Furthermore, persistent infrastructure deficits, including insufficient electricity supply and connectivity challenges, compound the difficulties farmers face when attempting to leverage ICT solutions effectively. Another significant barrier documented is the limited digital literacy and awareness among farming populations, especially older individuals. The literature underscores that older farmers frequently demonstrate lower levels of digital proficiency and awareness, manifesting as reluctance or reduced capability in utilizing digital technologies effectively. Issues such as difficulty navigating digital interfaces, limited trust in digital communication platforms, and insufficient awareness of ICT benefits further obstruct the comprehensive integration of these technologies within agricultural practices.

The results of this review demonstrate that ICT adoption consistently correlates with improved farmer welfare across multiple contexts, reinforcing evidence that digital and mobile technologies yield the strongest gains in income and productivity. Moreover, studies employing causal econometric methods report significant income increases from internet-based services and mobile communication; qualitative and descriptive research highlights non-monetary benefits such as enhanced social capital, food security, and subjective well-being. Although econometric analyses frequently demonstrate that ICT adoption correlates with measurable gains in farm productivity, emerging qualitative evidence underscores equally important non-monetary benefits that vary across agrarian contexts. For example, mobile communication technologies have been shown to streamline agricultural

operations and improve efficiency, albeit without directly quantifying income effects (Böttcher et al., 2023). In contrast, digital platforms foster social capital by facilitating peer networks and collective problem-solving, thereby strengthening community resilience (Hoang and Tran, 2023). Moreover, improved access to timely agronomic information via ICT contributes to enhanced food security and risk management, as farmers use weather forecasts and pest alerts to optimise production decisions (Pogonyshev et al., 2022). Beyond tangible outcomes, ICT engagement also promotes subjective well-being by increasing farmers' sense of connectedness and autonomy (Polyakov, 2021). These multifaceted impacts highlight the necessity of integrating both quantitative and qualitative measures when evaluating ICT interventions (Chao and Yu, 2023), especially given that effectiveness depends on local infrastructure, cultural practices, and demographic characteristics (Budiastuti et al., 2023). Finally, persistent digital divides, rooted in socioeconomic disparities and uneven access to technology, continue to shape adoption patterns and determine who benefits from ICT innovations (Abdulai, 2022).

Despite regional and technological differences, integrated ICT platforms, especially those with institutional support such as credit access and extension services, produce more substantial and sustained welfare improvements than basic mobile usage alone. Simultaneously, geographic inequalities in research output, particularly the concentration of studies in China, Ghana, and Nigeria, highlight potential limitations to the generalisability of findings. While primary survey data and causal econometric analyses provide strong evidence for income outcomes, the lack of rigorous evaluations of non-income dimensions highlights the need for diverse methods to fully understand ICT's impact on farmer welfare.

ICT adoption is frequently lauded for its potential to improve agricultural productivity and farmers' welfare. However, contrasting evidence suggests that its benefits are neither uniform nor guaranteed. For instance, Castle et al. (2021) demonstrate that agroforestry interventions enhanced productivity only under specific socio-economic and training conditions, indicating that ICT's effectiveness is contingent on contextual factors such as infrastructure and capacity building. Moreover, Alant and Bakare (2021) identify significant usability challenges among smallholder farmers with limited ICT literacy, which can impede the equitable realization of ICT's benefits. Similarly, Rajkhowa and Qaim (2021) argue that generic digital extension services often fail to address the localized information needs of farmers, thereby limiting improvements in productivity and welfare. Furthermore, Li et al. (2022) warn that over-reliance on digital tools risks marginalizing traditional knowledge systems that contribute to resilience when technological solutions fail. Financial barriers also constrain ICT adoption, as Yusuf et al. (2024) report that the costs associated with new technologies exacerbate disparities among resource-poor farmers.

Digital platforms and mobile communication may yield varying degrees of effectiveness depending on the specific characteristics of local agricultural systems and farmer demographics. For instance, studies in China show that internet-based solutions can facilitate off-farm employment and enhance household income, particularly where robust infrastructure and extension services are in place (Ma et al., 2020; Zhu et al., 2020). By contrast, smallholder farmers in settings with limited bandwidth or inconsistent network coverage, such as certain rural areas of Sub-Saharan Africa, appear to derive more immediate benefits from basic mobile communication tools that support market information systems (Okello et al., 2020; Siaw et al., 2020). Moreover, interventions involving smartphone applications have proven highly effective in regions where younger or more tech-literate farmers predominate (Bounkham et al., 2022). However, many studies reveal contrasting perspectives on ICT's broader societal impact. While ICT tools may provide rapid access to market information and agronomic expertise, they often necessitate stable infrastructure, ample financial resources, and a baseline of digital skills (Rajkhowa and Qaim, 2021). In regions where poverty and illiteracy rates are high, farmers may lack the means to purchase devices or the knowledge to navigate online services, thus reinforcing socio-economic divides instead of bridging them (Mtega, 2021). Similarly, concerns exist that a heightened emphasis on digital platforms could overshadow the value of traditional ecological knowledge, potentially creating reliance on external inputs and eroding local farming adaptations that have proven resilient across generations (Zulu et al., 2024). Critics also argue that fragmented approaches to digital adoption, focused narrowly on short-term productivity, can undermine long-term sustainability by neglecting site-specific soil, water, and cultural practices (Mapiye et al., 2021).

Education and digital literacy are key factors in helping farmers to adopt ICT. They underpin

farmers' capacity to adopt ICT by reducing perceived complexity and enhancing self-efficacy, thereby increasing both perceived usefulness and ease of use (Alant and Bakare, 2021). Formal education equips farmers with the cognitive skills needed to navigate digital interfaces and critically appraise online information, which in turn fosters confidence in technology use (Rajkhowa and Qaim, 2021). Likewise, digital literacy training improves practical competencies, such as interpreting market data and weather forecasts, thus directly influencing adoption decisions (Bounkham et al., 2022). Empirical evidence further indicates that farmers with higher literacy levels adopt ICT at significantly higher rates than less-educated peers, whereas low digital skills remain a key barrier, particularly among older cohorts (Camacho and Conover, 2019; Okello et al., 2020). Moreover, enhanced literacy mitigates information asymmetry by enabling farmers to exploit digital extension services more effectively, which supports more informed agronomic and marketing choices (Guo et al., 2018). Despite the recognised importance of formal education in facilitating ICT uptake, substantial disparities in digital knowledge endure among marginalised cohorts, most notably women and farmers with limited schooling (Byamukama et al., 2023). Furthermore, even when training initiatives are available, reluctance to engage with unfamiliar technologies frequently engenders inertia and impedes adoption (Li et al., 2022). Such behavioural resistance, coupled with persistent skill deficits and uneven resource availability, constrains the diffusion of ICT innovations across heterogeneous farming populations. These dynamics underscore the need for phased, context-sensitive implementation strategies that address both cognitive barriers and infrastructural deficits. Accordingly, effective policy design must integrate targeted capacity-building, inclusive pedagogical approaches, and incremental deployment of digital tools to ensure equitable access to ICT benefits irrespective of farmers' educational attainment or locale.

The reviewed studies show a complex interaction of enabling and restricting factors that influence farmers' ICT adoption. The most common drivers are formal education and digital literacy, as higher education equips farmers with cognitive skills to navigate digital interfaces and comprehend agronomic data. ICT use is higher among younger people and people who have used technology before. This is because these groups tend to be more confident in their abilities and more open to new ideas. Institutional supports, such as government-led infrastructure upgrades, extension services, and finance access, reduce transaction costs and enhance network availability, facilitating adoption. This finding is consistent with previous research, which has shown that education improves farmers' technological skills. Alant and Bakare (2021) demonstrate that farmers with higher educational attainment tend to exhibit stronger ICT literacy, enabling them to effectively access and apply information for agricultural decision-making. Next, Abdulai (2022) also shows that farmers with better digital skills more actively engage with digital platforms, improving their participation in agricultural services. Moreover, researchers have highlighted the pivotal role of targeted training programs in complementing formal education. Dhehibi et al. (2023) report that digital skill enhancement through structured interventions equips farmers with not only technical knowledge but also the confidence required for active ICT utilization. This evidence indicates that education and training do not operate independently but mutually reinforce farmers' ability to adopt ICT successfully.

On the other hand, financial constraints serve as a significant barrier: elevated initial expenses for smartphones and data services disproportionately impact low-income farmers, while ongoing deficiencies in network coverage and electricity supply in rural regions restrict effective ICT utilisation. Moreover, the restricted digital competencies of older and less-educated farmers, along with a lack of trust in digital platforms, exacerbate barriers to usage despite the presence of technology. These findings highlight the necessity for comprehensive strategies that target both human capital development and infrastructural deficiencies to facilitate equitable ICT adoption in agricultural communities. This suggests that education and digital literacy alone do not guarantee widespread adoption. Dhungana (2024) identifies socio-economic constraints, including poverty and limited infrastructure, as persistent barriers, even for digitally literate farmers. Sunam et al. (2024) further reveal that older farmers tend to adopt ICT at lower rates due to low digital readiness, despite their educational background. Additionally, Dhehibi et al. (2023) argue that when educational content lacks relevance to the practical realities of rural agriculture, farmers may struggle to translate knowledge into effective ICT use.

The reviewed studies indicate a clear pattern regarding the impact of ICT adoption on enhancing

farmers' welfare; however, certain limitations exist that could provide valuable insights for future research. Many studies employed cross-sectional designs, which limit causal inference and understate long-term effects. Some studies relied on region-specific samples, thus reducing generalisability and overlooking variations in infrastructure or social contexts (Bounkham et al., 2022; Zhu et al., 2020). Several studies also lacked standardised measures for welfare indicators and placed greater emphasis on income-based metrics than non-monetary outcomes. Furthermore, some interventions targeted younger or better-educated individuals, leaving older or less-literate farmers underrepresented (Aker and Ksoll, 2016; Guo et al., 2018). In addition, many studies did not control for potential endogeneity or selection bias, so their estimates may not fully capture the effects of ICT adoption in heterogeneous farming populations.

Conclusion

This systematic review confirms that ICT adoption is a transformative force for improving farmers' welfare, particularly through its capacity to enhance income, food security, livelihood assets, and social capital. However, the impacts are neither automatic nor universal. Evidence reveals that digital and mobile technologies yield the most significant welfare gains when integrated with institutional supports such as credit access, extension services, and market linkages. Farmers benefit not only economically but also socially and psychologically, as ICT facilitates better information access, stronger networks, and greater autonomy in decision-making. Yet, the digital divide rooted in infrastructure gaps, affordability constraints, and digital illiteracy continues to marginalize vulnerable groups, particularly the poor, the elderly, and less-educated farmers. Moreover, research remains disproportionately concentrated in a few countries, limiting the generalizability of insights and leaving critical gaps in understanding ICT's role in diverse agroecological and socio-cultural contexts.

Moving forward, future research must go beyond income-centric evaluations to capture the broader and long-term welfare dimensions of ICT adoption. Rigorous longitudinal studies and mixed-method approaches are urgently needed to unpack how ICT interacts with local realities, institutional arrangements, and farmers' lived experiences. It is equally vital to expand research coverage to underrepresented regions, particularly Southeast Asia, Latin America, and marginalized rural communities worldwide. Future interventions should focus on designing context-sensitive ICT solutions that are affordable, literacy-friendly, and compatible with limited infrastructure. Crucially, future studies must assess how bundling ICT with financial inclusion, extension services, and capacity-building programs can deliver not just higher incomes, but resilience, empowerment, and sustainable rural transformation.

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