Journal of Agriculture and Food Research 18 (2024) 101286

Contents lists available at ScienceDirect

Journal of Agriculture and Food Research

journal homepage: www.sciencedirect.com/journal/journal-of-agriculture-and-food-research

Digitalisation in agriculture: A scoping review of technologies in practice, challenges, and opportunities for smallholder farmers in sub-saharan africa

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ARTICLE INFO

Keywords:
Digital agriculture
Digital technologies
Sustainable agriculture
Smart agriculture

ABSTRACT

Digitalisation in agriculture is transforming the way farming is practised worldwide, and its potential benefits for smallholder farmers in sub-Saharan Africa (SSA) are particularly promising. Yet, scientific evidence on the digital technologies utilised by smallholder food producers in SSA and the associated challenges still needs improvement. This review attempts to provide a thorough overview of the technologies currently being employed by smallholder farmers in SSA while also exploring the associated challenges and opportunities. Through a systematic literature search, 27 relevant studies were analysed to identify the region-wise current technologies, challenges, and opportunities. Results show that various digital technologies are employed, including digital extension services and digital marketing of agricultural products. These technologies improve access to information and markets and enhance productivity. However, challenges hinder widespread adoption. Limited internet connectivity, low digital literacy, inadequate infrastructure, and affordability issues impede progress. Gender disparities further limit the equitable distribution of digitalisation benefits. Despite these challenges, significant opportunities arise from adopting digital technologies. The potential advantages are market access, better decision-making capabilities, and increased income and livelihoods. Digitalisation offers transformative possibilities for smallholder farmers in SSA. Overcoming barriers such as limited connectivity and low digital literacy is crucial. By harnessing the opportunities digital technologies can offer, the livelihoods of smallholder farmers can be uplifted, contributing to the growth of agriculture in SSA.

1. Introduction

Digitalisation, the term for the growing use of digital technologies, is fast changing many aspects of the economy, including agriculture. In agriculture, digitalisation is revolutionising the industry by improving the productivity, efficiency, and sustainability of how food is grown [1,2]. In the global north, digital technologies improve farm-level decision-making by giving farmers access to real-time weather, market pricing, and agricultural extension services. For example, in China, unmanned aerial vehicles (UAVs) are being utilised to identify weeds and facilitate early removal (Wang et al., 2022), while in Germany, robots are being used to milk cattle, saving labour and time (Langer & Kühl, 2023). However, Sub-Saharan Africa (SSA) has not experienced similar progress in the digitalisation of agriculture and still lags in applying digital technologies in agriculture [3].

In SSA, where agriculture is a critical sector that employs a large part of the population (Shimeles et al., 2018), digitalisation offers opportunities to overcome some of the challenges experienced by smallholder

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https://doi.org/10.1016/j.jafr.2024.101286
Received 21 February 2024; Received in revised form 3 June 2024; Accepted 5 July 2024
Available online 8 July 2024

producers [4,5]. Smallholder farmers account for around 80 per cent of the agricultural labour force in SSA and produce about 90 per cent of the region's food [6]. Yet, many smallholder farmers face substantial barriers, including limited access to information on markets and weather, limited access to credit, inadequate agricultural extension services, high internet costs and poor network coverage [7,8].

While there is growing interest in digital agriculture in SSA, there is limited observed evidence on the type of digital technologies farmers are using and the subsequent challenges they face in using those technologies [9–11]. Many smallholder farmers in the region still need help to afford essential digital tools like smartphones and computers and have limited awareness and knowledge of using digital tools effectively [9,12]. Adoption and usage rates of digital technologies in agriculture remain low [13], and there needs to be a greater understanding of the digital divide and its implications for smallholder farmers [14]. The digital divide refers to unequal access to digital technology, including smartphones, tablets, laptops, and the Internet (Shenglin et al., 2022). Further research is required to address these gaps and inform policies and interventions that promote the equitable and sustainable use of digital technologies by smallholder farmers in SSA.

By defining the kinds of digital technologies utilised in practice by smallholder farmers, how they are used, and the difficulties they encounter while employing digital technology for agriculture, this study adds to the empirical knowledge on digitalisation in SSA smallholder agricultural systems. Mainly, this review aims to address the following research questions.

(i) What digital technologies and services are smallholder farmers using in sub-Saharan Africa?
(ii) What challenges do smallholder farmers encounter when applying digital tools for agriculture? and
(iii) What policy suggestions may be made in light of the digital tools that smallholder farmers in SSA are using?

The researchers organised the paper as follows. Section 2 details the methods used in selecting the articles for review. In Section 3, the outcomes of the review procedure, as well as the challenges and opportunities for smallholder farmers, are presented and discussed. Section 4 concludes the review and suggests recommendations for policy and research.

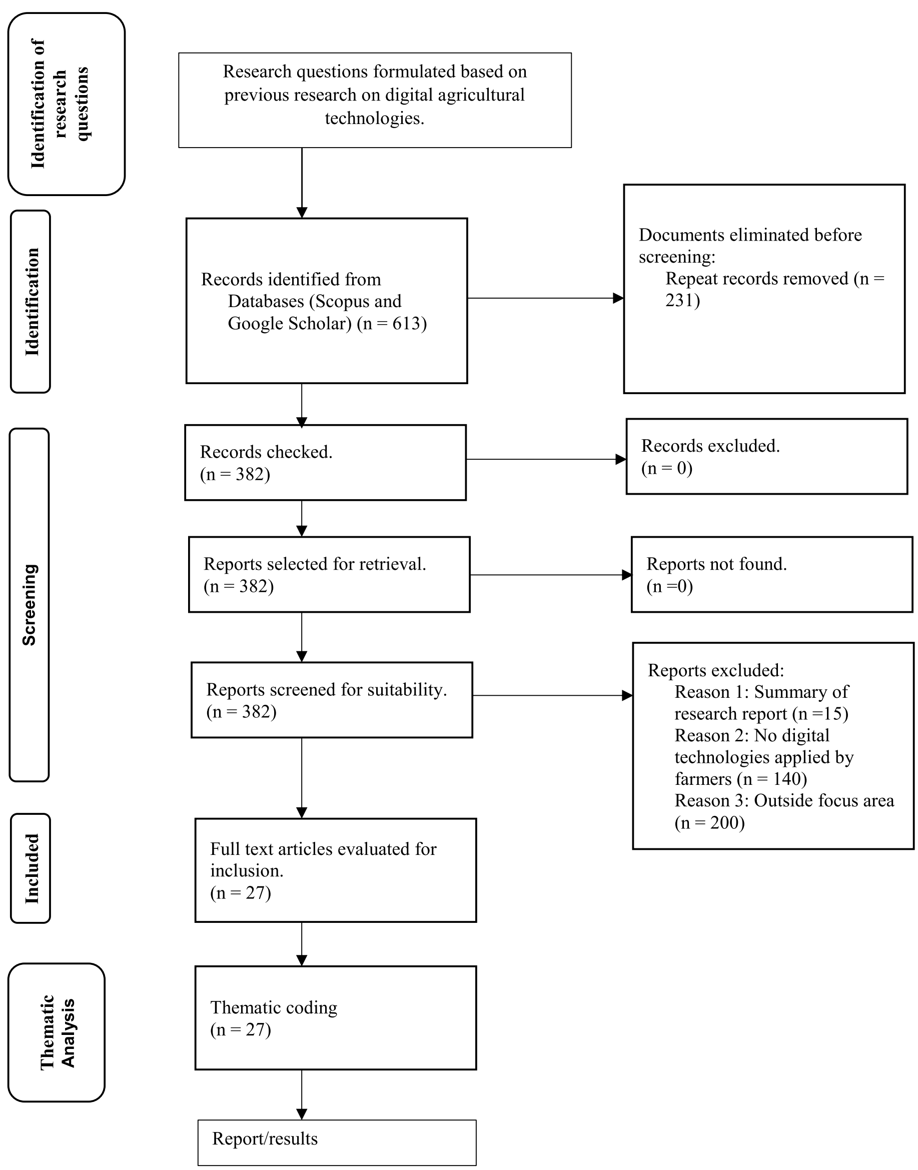

Fig. 1. PRISMA flow diagram showing a selection of studies and reasons for exclusion in the scoping review process.

2. Methods

A scoping review was conducted based on the methods outlined by Arksey and O'Malley [15] and presented according to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) guidelines [16]. The review process, illustrated in Fig. 1, comprised of the following steps: (i) developing the research questions (Section 1, Introduction), (ii) defining selection criteria for studies, conducting keyword searches in electronic databases, and carrying out full-text reviews (iii) thematic analysis of the selected studies and (iv) reporting results. The steps followed in the review process are outlined in sections 2.1, 2.2 and 2.3).

2.1. Development of research questions

Previous research has indicated that while global popularity for digital agriculture is high, there is limited evidence on what smallholder farmers are currently using digital technologies in SSA [17–19]. While the number of studies investigating the uptake and use of digital technologies in agricultural systems has increased, digitalisation trends regarding smallholder farmers still need to be expanded. This review aims to show evidence of the type of digital technologies in practical use in SSA smallholder agricultural systems.

2.2. Literature search and screening

A search for literature in English was carried out in three electronic databases: Google Scholar, SCOPUS and Web of Science. To reflect current knowledge, the literature was limited to studies conducted in SSA between January 2012 and September 2023. A search strategy using keyword combinations of frequently used agricultural terminologies was used. The keyword combinations are shown in Table 1.

2.3. Thematic analysis

In this scoping review, a thematic analysis procedure based on Braun and Clarke's [20] six-step approach was employed to systematically analyse the selected studies and identify the digital technologies that smallholder farmers were using, the challenges and opportunities confronting smallholder farmers in using digital technologies in SSA and the digitalisation of agriculture opportunities for smallholder farmers.

Through a systematic coding process, meaningful units of information related to i) the digital technologies being employed by smallholder farmers, ii) the challenges of using digital technologies, and iii) the opportunities faced by smallholder farmers in using digital technologies were identified. Coding was done in an Excel sheet that included the digital technologies, clusters, and articles in which the technology had been used. The systematic approach ensured that the analysis was comprehensive, rigorous, and reflective of the selected studies, thus enhancing the validity and reliability of the findings.

3. Results and discussion

From the 613 articles identified from the databases, 231 records were removed as duplicates, leaving 382 records to be screened for eligibility. The screening process resulted in 355 records being excluded, resulting in 27 studies being selected for full-text assessment. The records selected for full-text assessment studies were imported into the Mendeley reference manager. No studies were excluded in the full-text evaluation, and all 27 papers were selected for thematic analysis.

3.1. Overview of studies

Since 2012, the number of studies on digital agriculture has steadily increased (Fig. 2). Fourteen countries were represented in the literature. Fig. 3 shows the countries of the studies identified in the review. Each country had at least one study in which smallholder farmers applied digital technologies.

The increasing number of publications in this field from 2012 to 2023 reflects the growing interest in and recognition of the importance of the digitalisation of agriculture in SSA. Researchers, policymakers, and organisations have become increasingly aware of the potential of digital technologies to address the region's agricultural challenges. Also, the COVID-19 pandemic, which began in late 2019, highlighted the need for resilient agricultural systems. Digital agriculture solutions gained prominence during the pandemic by offering ways to support farmers even when physical access was limited (McKinsey, 2021).

3.2. Digital technologies in use

The thematic analysis showed that the digital technologies being applied by smallholder farmers could be broadly classified into four themes: digital financial services, digital extension services, digital farm management and digital marketing (Table 2).

The results of this review shed light on the digitalisation of agriculture in SSA with a particular focus on the technologies used and the challenges smallholder farmers face. Results show that the major digital technologies used by most smallholder farmers are 'simple' digital technologies that mostly require the possession of a mobile handset. The limited use of complex technologies such as drones and robots by smallholder farmers can be explained partly by the high cost of technologies such as drones that are still beyond the reach of many smallholder farmers and partly by smallholder farmers' limited knowledge of what technologies are available to them and how to use them. By bridging information gaps between various value chain actors, improving access to services in geographically inaccessible places, and promoting fair trade, market accessibility, and social and financial inclusion, digital technologies open up new possibilities for service

Table 1
Keywords and search strategy combination.

Keywords digital agriculture, precision agriculture, smart farming, smallholder farmers, and sub-Saharan Africa

Boolean Search ("Smallholder farmers" **OR** "smallholders" **OR** "Emerging farmers" **OR** "Subsistence farmers") **AND** ("agriculture*") **AND** ("Digital agriculture" **OR** "Digital technologies" **OR** "Machine Learning*" **OR** "Artificial Intelligence*" **OR** "Internet of Things" OR "ICT" **OR** "IoT" **OR** "Digital services" **OR** "Cloud Computing" **OR** "Big Data" **OR** "Precision agriculture" **OR** "Smart farming" **OR** ″ Data Analytics " **OR** "Smart Agriculture" **OR** "Agriculture 4.0″ **OR** "Blockchain" **OR** "Precision Farming" **OR** "Controlled environment agriculture") **AND** ("sub-Saharan Africa" **OR** "SSA")

Inclusion criteria

1. Studies in English published between 2012 and 2023.
2. Studies that focused on the direct application of digital technologies (e.g., drones, mobile phones, sensors, machine learning, information communication technologies (ICT), climate-smart farming, artificial intelligence (AI), and digital extension services) by smallholder farmers in sub-Saharan Africa.

Exclusion criteria

1. Conference proceedings, abstracts, editorials, personal opinions and book reviews.
2. Experiments or field trials conducted by researchers.
3. Articles not in English.

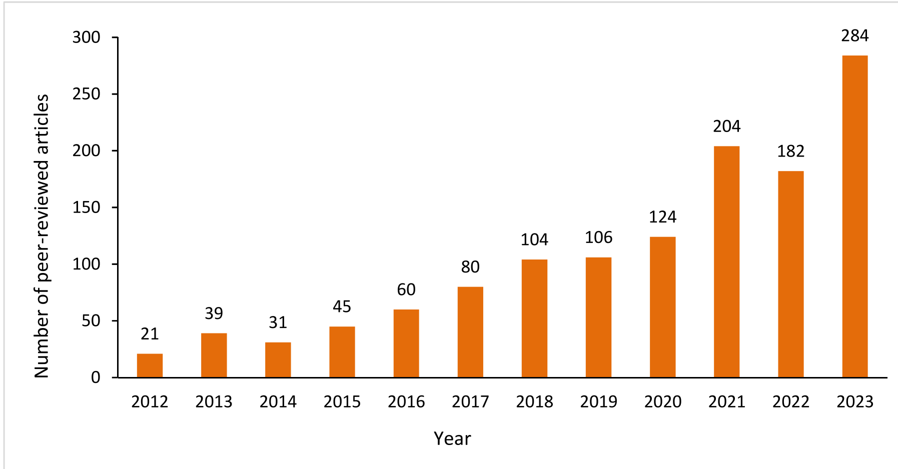

Fig. 2. Number of articles published each year (2012–2023) on digital agriculture and smallholder agriculture systems in SSA. The search was conducted for 2012–2020 using keywords and alternate terms in Table 1.

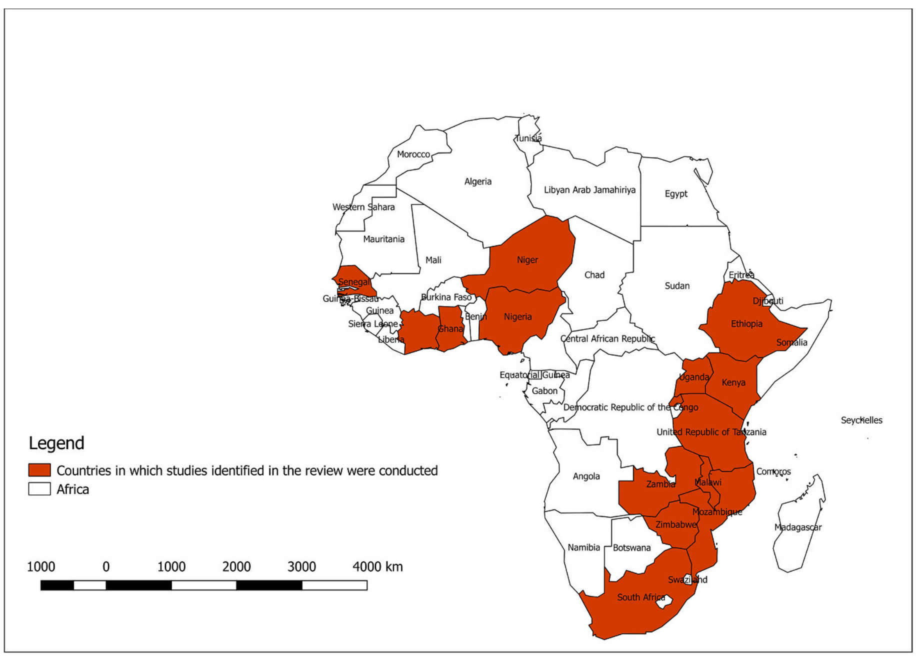

Fig. 3. Map of Africa showing studies in which smallholder farmers applied digital technologies in agriculture. (2012–2023).

Table 2
Smallholder farmers in SSA apply digital technologies and services.

Technology/Service	Application	Reference/Study
Digital financial services	Mobile Money Credit access	[10,21–28]
Digital farm management	Weather forecasts Mechanisation Soil water monitoring Pest management	[13,29–32]
Digital marketing	Market access Price alerts	[33–39]
Digital extension services	Digital extension	[9,19,40–43]

delivery. (FAO, 2021). However, several challenges must be addressed to realise the benefits of digitalisation in agriculture fully. The review results are summarised and discussed below according to the four themes emerging from the review.

3.2.1. Digital extension services

Digital extension services use digital technologies, such as cell phones, web-based platforms, and social media, to disseminate agricultural information and provide advisory services to farmers. These services can include information on crop management, market access, and weather forecasting. In this review, Marwa et al. [44] used a random sample of 457 smallholder producers, comprising 209 farmers frequently using the iCow application and 248 non-users. iCow (https://icow.co.ke/), a popular service in Kenya, is an integrated collection of services and tools that leverages ICT and partnerships with farmers to improve the productivity of smallholder farming systems through regenerative practices. Marwa et al. [44] showed that iCow users generally had a higher average annual milk production per cow than non-iCow users. Further, iCow users had, on average, higher income from livestock than non-iCow users. However, the study by Marwa [40] was cross-sectional, which limits the generalisability of the results.

In Rwanda, McCampbell et al. [41] explored the capacity of smallholder banana farmers to adopt and use digital technologies, particularly cellphone-based services, for digital extension. In the study, smallholder farmers were evaluated on their use of internet information, such as weather forecasts and access to digital extension services [41]. found that many smallholder farmers needed more training to utilise phone-based extension programs due to low digital literacy [41]. suggested the need for building local digital capacity through farmer training on using smartphones to access digital farming information.

Silvestri et al. [45] carried out a study in Tanzania to assess the impact of SMS coupled with the radio on smallholder farmers' adoption of sustainable agricultural intensification (SAI) methods. The results of the study by Silvestri et al. [45] showed that using SMS in combination with radio increased farmers' awareness of and adoption of SAI practices. However [45], also emphasised that other factors, such as education and land size, played a role in facilitating smallholder farmers' uptake of SAI practices.

Digital advisory and extension services have emerged as vital tools for providing smallholder farmers with valuable information and support. Similar studies have highlighted the positive impact of mobile-based advisory services on farmers' knowledge and decision-making methods (Labrique et al., 2013; Kuriakose et al., 2019). Farmers can receive timely weather forecasts, crop management practices, and pest and disease control strategies by accessing digital platforms like mobile applications or SMS services. These services empower smallholders to make educated decisions and improve their farming systems.

Research by McCampbell et al. [41] and Agyekumhene et al. [21] emphasise the potential of digital advisory and extension services to increase farmers' access to timely and relevant information. These technologies provide real-time weather updates, pest and disease management advice, and crop-specific guidance. They have the potential to enhance productivity, reduce risks, and increase smallholders' resilience. However, low digital literacy among farmers, particularly women and older individuals, remains a significant challenge [13]. Addressing this issue requires targeted capacity-building programs and tailored training materials to enhance farmers' utilisation of digital technologies and maximise the benefits of digital advisory and extension services.

3.2.2. Digital financial services

Digital Financial goods and services provided via digital channels, including smartphones, the Internet, and other electronic devices, are referred to as digital financial services (DFS) (Ebong & George, 2021). A vast array of financial services, including payments, savings, credit, insurance, and remittances, are included in DFS. In this review, the research by Agyekumhene et al. [21] explored the utilisation of Agro-Tech Smartex, an app designed to improve farm business and productivity for smallholder farmers through access to credit and a more comprehensive network of traders. Agyekumhene et al. [21] found that through AgroTech, farmers had improved record keeping and enabled smallholder farmers to attract large produce buyers and chicken feed producers.

Similarly, in Kenya, Kikulwe et al. [23] found that DFS, especially mobile money users, marketed a higher fraction of their produce and had more profits than non-users of digital technology. Kikulwe et al. [23] claimed that mobile money could help smallholder farmers gain better market access. In Uganda, Sekabira and Qaim [28] hypothesised that mobile money services could help smallholder farmers access higher-value markets with higher product prices. The research by Sekabira and Qaim [28] showed that adopting digital financial services (mobile money) enabled smallholder farmers to earn higher through transactions with buyers beyond their local area. However, the study by Parlasca et al. [26] in Kenya found that while more than 80 % of farmers used DFS, only 15 % used DFS for agriculture-related business. Parlasca et al. [26], concluded that DFS were yet to have a significant financial impact on smallholder farming systems in Kenya.

In line with our findings, previous research has highlighted the significance of DFS for smallholder farmers in SSA. The study by Kikulwe et al. (2019) demonstrated that digital financial services, including mobile banking, microfinance, and digital payment systems, contribute to financial inclusion and empower farmers by providing access to credit, savings, and secure transactions. These services enable farmers to overcome traditional barriers to financial services, improving their ability to invest in inputs, equipment, and other farming necessities.

Kikulwe et al. [23] and Parlasca et al. [26] highlighted their potential in facilitating agricultural transactions, accessing credit, and expanding market opportunities. These technologies reduce transaction costs, improve efficiency, and enhance farmers' access to formal financial services. However, obstacles like limited mobile network coverage, insufficient infrastructure, and low trust in digital platforms persist [33]. To address these challenges, collaboration between financial institutions, governments, and technology providers is crucial to expand network coverage, enhance infrastructure, and build trust in digital financial services among smallholder farmers.

3.2.3. Digital marketing

In an agricultural context, digital marketing is the promotion of agricultural products through digital platforms such as the Internet, social platforms, and television [46]. In this review, Coggins et al. [9] surveyed horticultural farmers in Kenya and found that 32 % used digital platforms to communicate with potential buyers. The communication involved negotiations about price, quantities, transport logistics and modes of payment. However, Coggins et al. [9] also found that simple phone functions (calling and texting) remained the primary mode of market-based interactions with business partners.

In Niger, Aker and Ksoll [34] studied the use of mobile phones and access to markets by smallholder farmers and revealed that smallholder farmers who received a cellphone and learned how to operate cellphones increased the range of crops they grew and were likely to be engaged in selling some of their crops. However, Aker and Ksoll [34] found no statistically significant effects on the amount and number of crops grown and sold by a farmer.

In Ghana, Hildebrandt et al. [36] investigated the effect of text-messages-based commodity prices of a Market Information Service (MIS) managed by a private company. The MIS gave subscribers weekly SMS price alerts of agricultural commodities. Hildebrandt et al. [36] found that providing commodity pricing information to smallholder farmers led to a 9 % growth in the prices received by farmers for yams. However, while [36] found that more than price alerts are needed to increase farmers' profitability, consideration of other factors, such as access to credit, markets and transport infrastructure, was also important.

Digital marketing platforms have also been recognised as powerful tools for smallholder farmers to connect with buyers, expand their market reach, and obtain fair prices for their produce. Studies by Njagi et al. (2020) and Katungi et al. (2019) have demonstrated that online marketing platforms enable farmers to overcome geographical constraints, reduce transaction costs, and access real-time market information. By leveraging these platforms, farmers can enhance their bargaining power, reduce post-harvest losses, and ultimately increase their profitability.

During the COVID-19 pandemic, e-commerce platforms played a crucial role in supporting farmers. These platforms served as lifelines for farmers, enabling them to access inputs, sell their commodities, and sustain their agricultural activities despite the disruptions caused by lockdowns and supply chain challenges. Farmers could procure essential agricultural inputs through digital channels, ensuring the continuity of their farming operations. Simultaneously, they could market and sell their produce online, reaching a broader customer base even when physical markets were constrained.

The significance of e-commerce platforms lies in their ability to help farmers overcome geographical constraints, reduce transaction costs, and access real-time market information, as highlighted by Njagi et al. (2020) and Katungi et al. (2019). By leveraging these platforms, farmers can enhance their bargaining power, reduce post-harvest losses, and ultimately increase their profitability. This digital transformation not only boosts the resilience of smallholder farmers but also contributes to food security and economic stability, especially during crisis times like the COVID-19 pandemic.

3.2.4. Digital farm management

Digital farm management refers to the use of technology, software, and digital tools to improve various aspects of farm operations, including planning, monitoring, and decision-making [47]. Examples of digital farm management include using real-time sensors, satellite monitoring of crop health, and automation of farm operations. This review revealed a few examples of smallholder farmers in SSA applying digital farm management technologies such as drones and satellites for farming.

In Tanzania, Mdemu et al. [30] investigated the impact of using soil moisture monitoring sensors in improving farmers' income and food security. Using data from farmers' field data books, Mdemu et al. [30] found that the use of soil moisture monitoring tools increased smallholder farmers' food security and household income. Farmers who had soil water monitoring tools were able to adjust the frequency and duration of irrigation to match plant needs. In addition, farmers saved time through reduced irrigation and had more time to focus on other farm management activities such as weeding and income-generating projects. Similarly, in Zimbabwe, Stirzaker et al. [48] developed a soil moisture sensor linked to a hand-held reader with LED lights that gave an image of soil moisture levels from the top to the bottom of the soil profile. The farmers were then trained to install and take readings from the sensors. In addition, Stirzaker et al. [48] found that farmers could use the moisture sensors to provide water to crops timely and keep the root zones wet enough to support higher harvests. This study also recorded substantial changes in farmers' irrigation management practices that spread to other farmers in surrounding regions.

Although the results of this review indicate that digital farm management technologies are less prevalent among smallholder farmers in SSA, their potential benefits should be considered. Research by Mugoya et al. (2020) and Obare et al. (2019) have highlighted the positive impact of digital farm management technologies, such as sensor-based systems and farm management software, on resource optimisation, productivity improvement, and sustainable agricultural practices. These technologies enable smallholders to make sound decisions concerning inputs, water management, and crop rotation, increasing efficiency and reducing environmental impact.

3.3. Challenges to using digital technologies

This section describes the critical challenges smallholder farmers face when using digital technologies for agriculture in sub-Saharan Africa. The review process revealed three central challenges to using digital technologies, namely (i) low digital literacy skills among smallholder farmers, (ii) inadequate digital infrastructure, (iii) the digital gender divide and (iv) financial costs associated with digital technologies.

3.3.1. Low digital literacy skills among smallholder farmers

Digital literacy is often defined as a person's ability to evaluate, find information, and communicate information through typing and other media on various digital platforms (Glister, 1997). In this review, several studies [see, for example, Coggins et al. [9]; Daum et al. [17]; Stirzaker et al. [48] highlighted low digital literacy among many smallholder farmers as a barrier to using digital technologies effectively. In the study by Daum and Birner, 2017, while the Hello Tractor app reduced the transaction costs associated with hiring tractor services, many farmers needed help to complete the booking of a tractor on the Hello Tractor app due to literacy issues. However, using agents resulted in distrust where farmers were reluctant to pay the commitment fee before the tractor arrived, fearing that the services would not be delivered. Similarly, in the evaluation of the AgroTech app by Agyekumhene et al. [21], a significant challenge was using agents as intermediaries in assisting farmers in using the app, necessitated by low farmer literacy and limited access to smart devices.

Coggins et al. [9] found that most of the farmers in their study had a limited ability to read, which constrained access to digital extension material. In addition, most farmers had difficulty navigating digital menus, downloading apps and opening hyperlinks. Tambo et al. [43], in their research on the utilisation of ICT by farmers, recommended including more videos, images, and voice-based approaches in populations with low digital literacy capabilities and in Msinga, KwaZulu-Natal, South Africa, Alant and Bakare [13] assessed the ICT literacy levels of 35 farmers in an irrigation scheme to see whether there was any association between smallholder farmers' ICT knowledge skills and demographics, such as age and education. Alant and Bakare [13] discovered that while education level directly correlated with digital literacy, smallholder farmers' age and years of agricultural experience had a negative and inverse relationship with digital literacy. Alant and Bakare [13] determined that smallholder farmers in Msinga, South Africa, needed higher digital literacy skills to include ICT in their agricultural practices.

Many studies highlight the challenge of limited digital literacy among smallholder farmers, hindering their effective utilisation of digital tools. Agyekumhene et al. [21] and McCampbell et al. [41] emphasise the importance of farmers' digital skills in accessing and understanding information provided through online extension services. Additionally, Alant and Bakare [13] emphasise that farmers' ICT literacy levels significantly influence their adoption and effective use of ICT for weather forecasting. Gender disparities in digital literacy are also evident, with female farmers facing additional barriers [13]. To address this challenge, targeted capacity-building programs, tailored training materials, and gender-sensitive approaches are essential to improve farmers' digital literacy and enhance their ability to benefit from digital technologies.

Coggins et al. [9] also point out that many digital tool developers need to consider heterogeneity in user ability from the onset but will employ rigid assessment tools to test acceptability and adoption. Ferrari et al. [49] and Mahmud et al. [50] emphasised that the designs and functionality of current tools inevitably marginalise older farmers, making them less capable of utilising digital technologies than their younger counterparts. Hülür and Macdonald [51] points out a disconnect between digital tool designs and user groups. It is recognised that smallholders are quite heterogeneous, varying in positionality, not only in terms of geographical location but also in socioeconomic circumstances, human capital (e.g., literacy and numeracy), and social structure (e.g., facing different social norms around access to digital technology) [52–54]. Developers can increase use among marginalised farmer groups by recognising these individuals as other users via cooperative design or by creating flexible tools that allow for user creativity.

3.3.2. Inadequate digital infrastructure

Respondents from the study by Coggins et al. [9] highlighted that while mobile networks were often available, the network was often slow and unstable. In addition, internet data costs were not easily affordable. Freeman and Mubichi [10] also noted easy access to reliable electricity as a challenge to adopting digital technologies in rural sub-Saharan Africa. In the study by Freeman and Mubichi [10], few smallholder farmers had a television set, citing that there needed to be a reliable source of electricity. Several other studies used in the review also noted that inadequate digital infrastructure, such as limited electricity coverage, limited mobile network coverage and costly smartphones, were significant barriers to the adoption of digital technologies for farming by smallholder farmers [26,27,38].

Inadequate digital infrastructure, including limited access to reliable internet connectivity, remains a significant challenge for smallholder farmers in SSA. Insufficient network coverage, unreliable electricity supply, and poor internet connectivity are common challenges faced by farmers in rural areas [28,38]. Limited infrastructure affects farmers' access to digital platforms and hampers the real-time exchange of data and information necessary for decision-making and market participation [43]. These infrastructure constraints hinder the seamless use of digital tools for accessing market information, engaging in digital marketing platforms, and utilising digital financial services.

Renewable energy sources such as solar coupled with data-less devices can be used to improve smallholder farmers' access to electricity and mobile networks. Across SSA, solar markets are growing exponentially to meet latent rural demand [55,56]. Since grid extension is too expensive or unlikely to happen anytime soon, solar home systems have drawn much attention as a private sector paradigm for rural energy service expansion in developing nations. According to Modi [57], Senegalese farmers overcame issues of access to electricity by adopting solar photovoltaic (PV) technology, transforming the landscape of generating electricity directly from the sun in the last decade.

Townsend et al. [58] and Shenglin et al. [59] have underscored the need for infrastructure development initiatives, such as expanding internet connectivity and investing in rural telecommunications, to close the digital divide and ensure equitable access to digital solutions for all farmers. Hartmann et al. [35] emphasise the value of improving these infrastructure limitations to ensure equitable access to digital technologies among smallholder farmers, especially those in isolated rural regions. Investments in expanding network coverage, improving connectivity, and reducing data costs are crucial to overcoming this challenge.

3.3.3. Financial costs

Linked to poor digital infrastructure, another challenge in the review was the high price of data and digital tools such as smartphones, drones and sensors [9,24,34]. High upfront costs for smart devices, software, and internet connectivity were prohibitive for most farmers who needed more financial resources. Ongoing data plans, maintenance, and training expenses further strain their budgets. Affordability and cost-effectiveness of digital tools were critical considerations for farmers.

The cost implications associated with digital technologies pose significant challenges for smallholder farmers. High upfront costs of acquiring devices, software, and internet connectivity can be prohibitive for farmers with limited financial resources [9,34]. Moreover, ongoing data plans, maintenance, and training expenses (e.g., drone flying) add to the financial burden. Affordability remains a key consideration in designing and implementing digital tools for smallholder farmers [22,42].

While simple technologies are more likely to reach a more significant number of smallholder growers, they are less likely to offer customised assistance. Advanced technologies that utilise automated analytic systems (such as sensors, artificial intelligence, and modelling) produce targeted data but pose more accessibility challenges. As such, while better-off producers with higher material potential and digital literacy benefit from specialised counsel, marginalised smallholder producers are forced to receive generic information. In this instance, the disparity in access to digital technology between smallholders and more capitalized farmers generates knowledge hierarchies.

Addressing the challenge of financial costs in digital agriculture should be a priority for policymakers and development practitioners. Strategies should aim to reduce the initial expenses and ensure that the long-term financial burden is manageable for smallholder farmers. This may involve targeted subsidies, innovative financing models, and the development of low-cost, user-friendly digital solutions that align with the financial realities of small-scale agriculture. By alleviating these financial constraints, more farmers can participate in and benefit from the digital transformation of agriculture, ultimately contributing to improved livelihoods and food security.

3.3.4. Gender digital divide

Results of this review show that the relative uptake of digital technologies among women could be higher in SSA. McCampbell et al. [41] found a gender disparity in their study on banana farmers, where about 8 out of 10 internet users were male. McCampbell et al. [41] stated that interventions and smallholder farmers' capacity development were necessary for the equitable use and scaling of digital technology projects. Aker and Ksoll [34], in their study in Niger, provided farming households a shared access to cell phones and instruction on how to utilise them. The survey results by Aker and Ksoll [34] showed that households where women were literate were likely to grow more cash crops. This suggests that when women have access to technology and are trained to use it, they can actively participate in agricultural decision-making and improve their agricultural practices.

However, Aker and Ksoll [34] also found that women needed more options to visit markets and sell their harvest. This finding underscores the persistence of gender-related challenges, such as limited mobility and social constraints, which can affect women's ability to engage in the agricultural value chain fully. In the study of ICT use by smallholder farmers in rural Mozambique, Freeman and Mubichi [10] discovered that women were significantly less likely to use ICTs to get agricultural information and that men were more likely than women to own cell phones. The study in Mozambique corroborated the presence of a gender digital divide in agriculture. This divide could limit women's access to critical agricultural knowledge, market information, and extension services increasingly available through digital platforms.

Gender inequalities persist in the uptake and use of digital technologies for farming, as confirmed by previous research [60–63]. Studies have consistently shown that female farmers have less access to smartphones, mobile money services, and digital advisory platforms than men [19,28]. Societal norms and gender roles also contribute to gender inequalities in adopting digital technologies.

Women's limited mobility and time constraints due to household and caregiving responsibilities further constrain their participation in digital agricultural activities [19,28]. Coggins et al. [9] also pointed out that it's not that women do not want to use digital tools; it is that the types of tools and information shared are irrelevant to their roles (assigned or assumed) within the household and community. These factors create barriers to women's engagement in digital platforms and limit their opportunities to access vital information, financial services, and market opportunities. Addressing these gender disparities requires gender-responsive policies, targeted training programs, and the active involvement of women in the design and implementation of digital solutions.

Contrasting findings also exist in the literature, emphasising the need for context-specific interventions. For example, some studies have reported no significant gender differences in adopting and using digital technologies [21,23]. However, it is important to remember that these findings may vary depending on location, cultural norms, and the specific digital technology being examined.

3.4. Opportunities for smallholder farmers

Digital technologies offer numerous options for smallholder farmers in SSA to advance their farming practices, access markets, and enhance their livelihoods. Through the analysis of the selected studies, several key opportunities emerged and are described in the sections below.

3.4.1. Improved access to information and market opportunities

Access to accurate and timely agricultural data is critical for smallholder farmers to make informed decisions about their farming practices and market opportunities. Digital technologies like mobile phones and online platforms provide avenues for accessing agricultural information such as weather, commodity prices, and best agricultural practices. For instance, Aker et al. (2016) highlight how farmers in rural Africa can use mobile phone-based platforms to access commodity prices, leading to better economic choices and improved bargaining power. Similarly, Voss et al. [19] demonstrate the potential of e-commerce platforms to connect smallholder farmers with buyers, facilitating market access and reducing transaction costs.

3.4.2. Enhanced productivity and resource management

Digital technologies offer tools and applications to help smallholder farmers optimise their productivity and resource management. For example, precision agriculture techniques, including satellite imagery and remote sensing techniques, enable farmers to assess crop health, water needs, and nutrient requirements. This information can guide farmers in applying inputs more efficiently, improving yields and reducing resource wastage. Sekabira and Qaim [28] provide evidence of how mobile money in Uganda facilitates access to farming inputs, leading to increased harvests and off-farm income generation for smallholder farmers.

3.4.3. Climate change adaptation through digital technologies

Smallholder farmers in SSA are more susceptible to the effects of climate change because of limited resources. Digital technologies offer opportunities for climate change adaptation and resilience building. For example, remote sensing technologies can provide early warnings of weather patterns, enabling food producers to make sound decisions about crop management. Furthermore, mobile-based platforms can deliver climate-smart agriculture practices and advisory services to farmers, helping them adapt to changing environmental conditions. Foko et al. (2020) highlight and accentuate how digital technologies may help Cameroon adapt to climate change and practise sustainable agriculture.

3.4.4. Potential for enhanced income and livelihoods

Digital technologies can play a transformative role in enhancing smallholder farmers' income and livelihoods. Digital platforms enable farmers to sell their produce at fair prices, access credit, and engage in value-added activities by providing access to markets, information, and financial services. This can lead to increased incomes, improved food security, and decreased poverty. Aker et al. (2016) emphasised the potential of mobile money services in reducing transaction costs and facilitating financial inclusion for smallholder farmers. Additionally, Voss et al. [19] highlight how e-commerce platforms can contribute to income generation and market expansion for smallholder farmers in the horticulture sector.

3.5. Study limitations

Despite the rigorous approach employed in this scoping review, several limitations should be acknowledged. Firstly, including studies only in English may introduce a potential bias and limit the diversity of perspectives on the topic. Additionally, the scope of the review was focused on SSA, which may determine the applicability of results to other regions. Moreover, relying on published literature may exclude valuable insights from unpublished studies. Despite these limitations, this scoping review provides a comprehensive overview of the constraints and prospects of using digital technologies for smallholder farming systems. It lays a foundation for future research in this area.

4. Conclusion

This study highlights the prevalence of "simple" technologies, such as mobile-based extension and digital financial services, among smallholder farmers in SSA. Our findings show the digital technologies being used in practice in SSA and highlight how these technologies can potentially improve farming methods and farmers' lives. However, addressing challenges related to digital literacy, infrastructure, and gender inequalities is crucial for realising the full benefits of digitalisation in agriculture, with particular emphasis on a consolidated approach addressing these multi-pronged needs.

Collaboration among policymakers, development practitioners, and other relevant stakeholders is essential to implement context-specific interventions that foster digital inclusion, empower smallholder farmers, and promote sustainable regional agricultural development. Furthermore, the active engagement of the corporate sector, including telecom providers and technology companies, plays a pivotal role in these collaborations. Telecommunication providers, in particular, are key partners in expanding digital access and connectivity in rural areas, and their expertise in infrastructure development and service provision is invaluable.

The review of the selected studies showed several opportunities for smallholder farmers in SSA through digital technologies. These opportunities include increased productivity and resource management, better access to information and market opportunities, adaptation to climate change, and the possibility of higher income and better living conditions. By leveraging digital technologies, smallholder farmers can overcome some of the traditional barriers they face and take advantage of the transformative potential offered by the digital revolution in agriculture (Aker et al., 2016; [19]). However, it is essential to address the challenges of digital literacy, infrastructure, and gender inequalities to ensure these opportunities are accessible to all farmers, irrespective of their socioeconomic status or gender.

5. Policy recommendations

The results of this study have important policy implications for promoting the effective utilisation of digital technologies in smallholder farming systems in SSA. First, addressing the challenge of low digital literacy skills among smallholder farmers is crucial. Policy interventions should provide training programs and capacity-building initiatives to enhance farmers' digital literacy and skills [9,21]. This could include initiatives at the community level, such as training workshops, extension services, and farmer field schools, to guarantee that smallholder farmers are equipped with the necessary knowledge to use digital tools effectively. It is important to emphasise that these interventions should involve bottom-up engagement, ensuring that they are responsive to the genuine needs and preferences of the target community (Banda et al., 2020; Makhado et al., 2021).

Secondly, improving digital infrastructure is imperative to overcome the barriers associated with limited connectivity and access to digital technologies. Investments in improving the affordability and accessibility of smartphones and other digital devices and increasing internet coverage, especially in rural regions, should be a top priority for governments and policymakers [33,35]. The public and private sectors—including telecom companies—can create a robust digital infrastructure and guarantee that digital services are widely accessible and reasonably priced [24].

Furthermore, addressing gender inequalities is essential for promoting inclusive digitalisation in agriculture. Policies should empower women farmers by providing them equal access to digital technologies, information, and resources [28]. This could be achieved through targeted programs that focus on bridging the gender gap in digital literacy, providing training and support specifically tailored to women farmers, promoting gender-responsive agricultural policies and programs and the active involvement of women in the design and implementation of digital solutions [22,23].

Finally, it is crucial for policy interventions to promote an atmosphere that supports entrepreneurship and innovation in digital agriculture. This includes creating favourable regulatory frameworks that encourage developing and adopting digital technologies, incentivising public-private partnerships, and supporting local start-ups and technology-driven enterprises [19]. Legislators should encourage knowledge-sharing websites, networking events, and stakeholder partnerships to share best practices and lessons discovered while utilising digital agriculture technologies [29].

By addressing these policy implications, governments and policymakers can create an enabling environment that empowers smallholder farmers to effectively utilise digital technologies, overcome existing challenges, and capitalise on the opportunities presented by digitalisation in agriculture. Importantly, these policies should be designed and implemented to actively engage and respond to smallholder farming communities' unique needs and perspectives, ensuring their genuine participation and ownership in digitalisation.

6. Investing in research and innovation

Devoting resources to research and innovation is paramount to overcoming the challenges hindering SSA's digitalisation of smallholder farming systems. While policy interventions and infrastructure development are crucial, a deeper understanding of how digital technologies can effectively serve resource-constrained smallholder farmers is essential. Future research should not only evaluate the influence of digital technologies on productivity and income but also explore innovative, low-cost solutions tailored to the unique needs of these farmers, addressing the challenge of high digital tool costs that previous recommendations overlook. Collaboration among research institutions, technology developers, and stakeholders is vital to drive these efforts and assess digitalisation's socioeconomic and environmental impacts, furthering sustainable agricultural practices.

By investing in research and innovation, stakeholders can unlock digitalisation's full potential in smallholder agriculture, paving the way for increased productivity, improved livelihoods, and sustainable development across sub-Saharan Africa. This holistic approach ensures that digital technologies are accessible but also practical and affordable for the farmers who need them most, contributing to lasting positive change in the region.

CRediT authorship contribution statement

Dennis Junior Choruma: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Conceptualization. **Tinashe Lindel Dirwai:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Munyaradzi Junia Mutenje:** Writing – review & editing, Methodology, Investigation, Formal analysis. **Maysoun Mustafa:** Writing – review & editing, Visualization, Investigation, Formal analysis. **Vimbayi Grace Petrova Chimonyo:** Writing – review & editing, Visualization, Investigation. **Inga Jacobs-Mata:** Writing – review & editing, Visualization, Resources, Funding acquisition. **Tafadzwanashe Mabhaudhi:** Writing – review & editing, Supervision, Resources, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

The Centre for Transformative Agricultural and Food Systems of the University of KwaZulu-Natal is acknowledged for initiating and funding this work. This work was also funded, in part, by the Excellence in Agronomy and Ukama Ustawi Initiatives, which are grateful to the CGIAR Trust for funding.

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