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Unraveling heterogeneity in Farmers' adoption of Mobile Phone Technologies: A systematic review.

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Abstract

Adoption and usage of mobile phones enable information and knowledge flows among value chain players, including farmers, and therefore contribute to improved efficiency. To ensure the successful implementation of MPTs in agriculture, farmers should embrace them. We present a systematic review of determinants, constraints, methods, indicators, and measures of MPT adoption among farmers and a methodological quality assessment of the included studies. Findings from 53 studies showed significant heterogeneity in research. Most studies targeted developing regions in Africa and Asia and only a few in developed countries. Although studies mainly focused on MPT adoption, they varied significantly in the outcome indicators assessed and their measurement. This heterogeneity in the conceptualization and measurement of adoption indicators underscores the need for standardized approaches in future studies. There is also sub-optimal use of established psychological-behavioral theories to underpin MPT adoption. Cross-sectional designs and quantitative approaches dominate the research landscape. Concerning farmers' MPT adoption, key drivers were education, age, gender, perceived ease of use, perceived usefulness, perceived cost, performance and effort expectancy, attitude, skills, and knowledge. Factors such as mobile phone cost, inadequate infrastructure, and language barrier constitute major hurdles constraining farmers' adoption of MPT. The generally low quality of the reviewed studies suggests that future studies should invest in transparently providing the study objectives, methods, and interpretation of their findings. This systematic review contributes to a better understanding of farmers' MPT adoption drivers and suggests areas for future research. It provides relevant information to policy-makers, public and private sector agencies, mobile phone companies and app developers, researchers, agricultural extension workers, academicians, and other stakeholders when designing and implementing policies for MPT adoption in agriculture.

Keywords: Adoption, Farmers, Mobile phone Technology (MPTs), Quality appraisal; Mixed-Method Appraisal tool (MMAT), Systematic review

1. Introduction

The last two decades have seen a rapid advancement in the global use of information and communication technologies (ICT) (Aker, Ghosh, & Burrell, 2016). The Mobile Phone Technology (MPT) component of ICTs has spread incredibly quickly in both developed and developing countries, supposedly because of its cost-effectiveness, lower infrastructure demand, and relative ease of use (Kabbiri, Dora, Kumar, Elepu, & Gellynck, 2018). Existing research recognizes the critical roles played by MPTs, such as mobile (smart) phones and related applications (apps), in enhancing agricultural productivity among farmers (Ezeoha, Obi, Igwe, & Ezeruigbo, 2020; Schulz, Prior, Kahn, & Hinch, 2021).

Among these roles, MPTs facilitate fast communication via data, voice, and SMS services among farmers – connecting them to markets. Likewise, there is evidence that MPTs are crucial for addressing the issue of information asymmetry among farmers and other actors within the agricultural value chain and contribute to lowering farmers' transaction costs (Aker et al., 2016; Nakasone, Torero, & Minten, 2014). By increasing farmers' timely access to information on agricultural best practices, weather and disease forecasts, or market prices, mobile phones might boost agricultural yields and farmers' income (Okello, Kirui, Njiraini, & Gitonga, 2012). Existing research indicates that MPT use in agriculture could enhance social relationships among farmers (Baardewijk, 2017; Butt, 2015) and address barriers to traditional extension methods (Aldosari et al., 2017b). However, the adoption of such technologies among farmers remains low (Bonke, Fecke, Michels, & Musshoff, 2018).

Farmers' adoption of technology is complex and often involves a cognitive process that leads to a motivated decision on whether to adopt it or not (Shikuku, Okello, Sindi, Low, & McEwan, 2017). Extant literature highlights the intricate interaction of factors influencing farmers' decision-making (Shikuku et al., 2017). For example, Misaki et al., 2018 found that lack of trust and transparency, limited farmers' involvement in the early stages of invention, poor mobile infrastructure, and designing MPTs in foreign languages hinder mobile phone use by farmers in developing countries. Other factors influencing mobile technology adoption are age, sex, education, experience, and household size (Benjamin Yao Folitse, Manteaw, Dzandu, Obeng-Koranteng, & Bekoe, 2018). Despite the existence of a few theoretical and empirical research on farmers' adoption and use of MPTs, scientific understanding of the factors influencing the decision to own a mobile phone and utilize it for agricultural purposes remains limited (Asravor, Boakye, & Essuman, 2021). What is even less clear is the nature of the effects of these determinants on MPT adoption in farming (H. G. Hoang & Drysdale, 2021). Much uncertainty still exists about the relationship between various determinants and farmers' adoption of MPTs. For example, (S. P. Thar, Ramilan, Farquharson, Pang, & Chen, 2021) reported a negative effect of age on the use of MPTs by farmers. However, Benjamin Yao Folitse et al. (2018) found a positive effect, and other studies found no effect of age on MPT adoption (Krell et al., 2020; Sikundla, Mushunje, & Akinyemi, 2018). Similarly, the effect of education on MPT adoption is mixed. Education positively influenced MPT adoption in some studies (e.g., Mwalukasa, Mlozi, & Sanga, 2018; Nikam, Kumar, & Kingsly, 2021) and had no significant influence in other studies (Filippini, Marescotti, Demartini, & Gaviglio, 2020; Narine, Harder, & Roberts, 2019).

Besides the inconclusiveness of studies on the effect of various factors on technology adoption among farmers, they are also inconsistent with the indicators and measurement of adoption – thus presenting a methodological challenge. Owing to this complexity, the factors that drive farmers' adoption of MPTs must be understood. Such relevant insights would facilitate decision-making and implementation by policy makers, boost the uptake of MPTs, and subsequently generate better agricultural outcomes (Mwalupaso, Wang, Xu, & Tian, 2019).

Published reviews on ICTs, especially MPTs in agriculture, present several limitations. First, except for a few of these targeted reviews (e.g., Mendes et al., 2020; Misaki, Apiola, Gaiani, & Tedre, 2018; Pongnumkul, Chaovalit, & Surasvadi, 2015), most studies on this topic are non-systematic. Second, their focus is narrow and often restricted to one specific sub-sector of agriculture or mobile phone application, e.g., precision agriculture (Mendes et al., 2020); smartphone applications for the sustainability of agricultural landscapes (Inwood & Dale, 2019); specific mobile phone-enabled services among smallholder farmers (Baumüller, 2017) and pastoralists (Parlasca, 2021), smartphone-based sensors (Pongnumkul et al., 2015); or consider the general state of ICTs (Aker, 2011; Nakasone et al., 2014). Third, previous literature reviews on farmers' adoption of mobile phone technology services and applications have primarily targeted developing countries (e.g., Baumüller, 2017; Duncombe, 2015; Keerthi & Gautam, 2021; Misaki et al., 2018).

Thus, without disregarding the contributions of past studies on MPT, this review adds to the current body of knowledge by (1) focusing on MPT adoption among farmers and (2) evaluating the methodological quality of studies on farmer MPT adoption. The specific objectives of the study were to (a) analyze and synthesize the key determinants and constraints of MPT adoption among farmers; (b) evaluate the various measures, methods, and theories employed by studies to understand MPT adoption; (c) assess farmers' perception regarding different MPTs and their associated usage, (d) appraise study quality and (e) identify and suggest areas for future research and recommendations for scaling up MPT adoption among farmers. Our systematic review differs from past reviews on mobile phone technologies in four ways. Firstly, it provides the first study that uses a methodologically sound review procedure to systematically and comprehensively examine the adoption of MPT by farmers. Secondly, this is the first review to assess the methodological quality of farmers' MPT adoption studies based on the Mixed-Method appraisal tool. Thirdly, our review provides a deeper understanding of the various measures, methods, statistical techniques, and behavioral theories used to evaluate MPT adoption and its' motivations. Fourthly, the review considers the full range of smartphone applications, MPTs, and all types of farmers and includes studies from developing and developed country contexts, which provides a broader perspective of the determinants of MPT adoption. The result of this study will advance understanding of the critical factors influencing farmers' adoption and use of MPTs, which is vital for the conceptualization and measurement of prospective studies. Moreover, the findings are relevant for effectuating novel MPTs among farmers and the agricultural food chain.

2. Methodology

2.1 Literature search strategy

A systematic literature review of published evidence on farmers' adoption of MPT was undertaken using Moher, Liberati, Tetzlaff, and Altman (2009)'s PRISMA approach. Before launching the systematic review process, a review protocol was developed, registered, and published on Open Science Framework (DOI: 10.17605/OSF.IO/AGR6Y, available at https://osf.io/agr6)

In line with the general search strategy for systematic reviews, we applied a search query with keywords developed from literature (Aker, 2011; El Ayadi et al., 2020) and expert consultations in the Web of Science electronic database on 10th September 2021. To complete our dataset and identify studies that our electronic search strategy in the Web of Science database could have missed, we conducted a citation search of high-quality articles based on the MMAT criteria in google scholar. As an additional step, we examined the reference list of the included studies to identify more studies.

The search syntax used a combination of terms referring to "Farmers" or similar, "Adoption" or equivalent, and "Mobile phone Technology" or similar. Thus, the primary studies were identified using the following specific syntax: **Farm*** **OR** Smallholder* **OR** Small-holder* **OR** "Small holder*" **OR** "Primary producer*" **OR** "Small producer*" **OR** Agriculture **OR** Pastoral* **OR** "Farming household*" **OR** "Farm household*" **OR** "landholder*" **AND "mobile Phone*" OR** "Smartphone*" **OR** "Smart phone*" **OR** "Smart-phone*" **OR** "cellular" **OR** "cellphone*" **OR** "cell phone*" **OR** "cell-phone*" **OR** "mobile device***" OR** "smartphone-based***" OR** "Smartphone-enabled*" **OR** "mobile phone-based*" **OR** "Mobile Phone-enabled***" OR** "Mobile cellular*" **OR** "Mobile technol*" **OR** android* **OR** "ios" **OR** "Short Messaging Service*" **OR** SMS OR ICT* **OR** "mobile app*" **OR** "mobile application*" **OR** "Smart phone app*" **OR** "Smartphone app*" **OR** "smart-phone app*" **OR** "Smart phone application*" **OR** "Smartphone application*" OR "smart-phone application*" **AND Adopt* OR** use **OR** accepta* **OR** behavior* **OR** behaviour* **OR** choice **OR** choos* **OR** attitude* **OR** decision* **OR** "decision mak*" **OR** WTP **OR** willingness* Or willingness-to-pay **OR** willingness-to-accept **OR** WTA **OR** willingness-to-adopt **OR** willingness-to-try **OR** prefer*

2.2 Eligibility criteria and screening

The Joanna Briggs Institute's population, concept, and context (PCC) framework (see Table 1) was utilized to define the primary concepts of this study (Madlabana, Mashamba-Thompson, & Petersen, 2020). To be included in the review, studies had to meet all the inclusion criteria (see Supplementary Table 3), that is, studies published in peer-reviewed journals with full-text versions available, based on primary data, written in English, and focused on farmers as the target population, assessed adoption of MPT, and published from the year 2000 onwards when mobile phones started increasing rapidly across the globe, including in developing regions (Baumüller, 2017). We did not restrict studies based on the study design. Figure 1 shows the detailed PRISMA flow chart for the systematic review.

[Figure 1]

Our search in the web of science database yielded 4191 articles that we imported to Endnote Desktop (version X9). Once in Endnote, we removed nine duplicates and subjected the remaining articles to a rigorous selection process. This selection process involved the screening of (1) 4180 article titles for the presence of relevant keywords, (2) 90 abstracts to scrutinize further the relevance of studies, and (3) in-depth reading of the 65 full-text articles. At this stage, 30 articles met the inclusion criteria. In total, we identified 52 studies through the citation search in google scholar and reference list search, of which we eventually included 21 studies in the review after the screening process. We updated our electronic database search on 5th June 2022 and included two more articles. Thus, we extracted data from 53 studies (see supplementary Table 1).

2.3 Data extraction and analysis

Before data extraction, a standardized sheet was created in Microsoft Excel and utilized during the full-text review to facilitate coding details. This data extraction sheet captured different characteristics of the included studies (e.g., detailed reference, study settings), the mobile phone technology studied, sample characteristics, study methodology, adoption indicators and measurement, the determinants and constraints of adoption, and MMAT quality score of the included studies (see supplementary Table 4 for detailed information on extracted data).

The variation in methods, models, and adoption indicators employed to assess MPT adoption across the included studies made a statistical meta-analysis impossible. Thus, the systematic review adopted a summative approach (Grant & Booth, 2009) to compile and analyze the extracted data. Following Kamrath, Wesana, Broring, and De Steur (2019), a qualitative content analysis, often used in analyzing text data, was applied to categorize the variables used by the included studies. The percentages relating to the variables in Figure 2 are calculated based on the total number of included studies.

[Figure 2]

2.4 Appraising the quality of included studies

The methodological quality of the included studies was assessed using the well-established Mixed Method appraisal tool (MMAT), version 2018 (Hong et al., 2018). This approach facilitates the simultaneous appraisal of all research study designs, including mixed, quantitative, and qualitative methods (Crowe & Sheppard, 2011; Parikh, Aparo, Nordhagen, & De Steur, 2022). Additionally, the MMAT criteria enable the evaluation of study objectives, research questions, methodology, reporting, and discussion of results for appropriateness and clarity (Simera, Moher, Hoey, Schulz, & Altman, 2010).

Before assessing the methodological quality, the included studies were subjected to two screening questions: (1) Are there clear research questions? and (2) Do the collected data allow to address the research questions? Afterward, the studies were rated for the appropriate study design category as denoted – sections 1 for qualitative studies, 4 for quantitative descriptive studies, and 5 for mixed methods studies. A score of 1 was allotted to each question when it met the quality criteria, a score of 2 when it did

not meet the requirements, or a score of 3 when the reviewer could not tell (see footnote of supplementary Table 2 for the detailed MMAT checklist). Similar to Parikh et al. (2022), MMAT scores representing the number of criteria met (rated 'yes') were divided by five and translated into percentages. Studies scoring at least 4 (80%) are appraised as "high quality," scores between 3-4 (60-80%) are appraised as "moderate quality," and studies that scored below 3(60%) are considered to be of "low quality." Based on the recommendation of (Hong et al., 2018), this study neither calculated an overall quality score from the ratings of each criterion nor excluded studies with low methodology quality. Thus, unlike Pace et al. (2012), our quality appraisal aimed to illuminate the caliber of research on MPT adoption among farmers and inform the citation search stage. Supplementary Table 2 shows the detailed quality appraisal for the included studies.

3 Results

3.1 Study characteristics and methods

A total of 4243 studies were identified, of which 53 articles were included in the systematic review (Figure 1; Supplementary Table 1). The key characteristics are discussed below (see Table 5).

Publication year. The included articles were published from 2011 to 2022, with a clear trend of an increasing number of publications each year. 2021 had the highest number of published articles (n=11 equivalent to 22.6%)

Geographic distribution. More than half (53%) of the studies focused on Africa, followed by 28% in Asia, 13% in Europe, 4% in the Americas, and just 1.8% in Oceania (see Figure 2). Nigeria (n=7), Ghana, Ethiopia, and Tanzania, each with four studies, dominated farmer MPT studies on the African continent, while India (n=3), Bangladesh, Pakistan, and Vietnam, each with two studies, dominated studies on the Asian continent. Studies in Europe were dominated by Germany (n=4).

***Study settings*.** While 43% of the studies did not specify their setting, 47% targeted farmers in rural areas. Only 6% and 4% of the investigations targeted farmers in urban and peri-urban-rural regions, respectively.

Farming activity and production scale of farmers. Most studies (51%) included in this review neither specified the farming activity undertaken by the farmers nor the scale of production (64%). Nonetheless, the remaining 49% of studies targeted farmers engaged in crop production (21%), livestock production (17%), and mixed farming (11%). Regarding production scale, 30% of the targeted farmers were small-scale farmers (SSF), 2% were medium-scale farmers, and 4% of the studies targeted a mixture of small, medium, and large-scale farmers.

Research designs and methods. Three-quarters (75.4%) of the studies in this review utilized quantitative descriptive approaches to describe or analyze the factors associated with farmers' MPT adoption, while 19% applied mixed-method techniques, and 5.6 % were qualitative studies. All (100%) of the studies employed cross-sectional research designs. Although both developing and developed countries focused on mixed-method and quantitative descriptive approaches, qualitative methods were only applied by studies targeting developing countries.

The quantitative studies collected data on farmers' socio-demographic characteristics, perceptions, and attitudes about using mobile phone applications in farming, drivers, and constraints to MPT adoption. Most quantitative studies used face-to-face interviews aided by semi-structured and structured open-ended questionnaires to collect data. What was also fascinating was the increased use of mobile applications or software to collect research data among some quantitative descriptive studies. Examples of such software include CommCare (S. P. Thar et al., 2021), GeoODK mobile phone application (Molina-Maturano et al., 2021), and Qualtrics (Victor, Nic, & Xiaomeng, 2021). However, none of the studies reported on the effectiveness of such methods.

Sampling methods, including multi-stage procedures, random selection, convenience sampling, purposive sampling, systematic sampling, stratified systematic sampling, non-probability quota sampling, or a combination of one or more of the stated sampling methods, were used to identify study respondents.

Most (77%) of the quantitative descriptive studies analyzed their data using descriptive statistics such as means, percentages, and frequencies. Others (28%) used inferential statistics and different types of regression analyses (42%), including logistic regression, Tobit regression, linear regression, probit model, and other methods such as cluster analysis and structural equation modeling. It is worth noting that some studies did not specify their sampling procedures and the statistical techniques employed to analyze data. The qualitative studies employed similar sampling methods and obtained identical information as the quantitative ones through Focused group discussions (FGD), structured interview schedules, and Key Informant Interviews. These qualitative data were analyzed using ethnography, phenomenology, and thematic analysis applying inductive approaches to obtain qualitative data.

The mixed-method studies used a combination of quantitative and qualitative designs.

Types of MPTs. Most studies (36.9%) assessed the adoption of smartphones and mobile phones, while 26.4% of studies considered the adoption and use of smartphone applications supporting farmers' decision-making (DSAs) (see Table 2). Such DSAs included crop protection apps, mobile-based agricultural extension, Agri-info App, market information systems, herd/ livestock management apps, camera function apps, disease and weather forecast apps, and Agri (mobile-based advisory) apps. 24.5% of studies examined text-messaging (SMS) applications, 13.2% investigated social media applications such as Facebook, Twitter, IMO, and WhatsApp, and another 13.2% assessed applications that provide news and information. Other app categories (15%), such as call/video, geotag, finance, utility, and productivity, were reported at most twice. Developing country studies focused primarily on the generic use of mobile phones and targeted more basic phones and features such as text messaging and voice calling. On the other hand, developed country studies assessed smartphones and mobile applications with enhanced capabilities and computational power.

Application of behavioral theories. Less than half (43%) of the reviewed studies utilized behavioral/psychological theories to unravel MPT adoption among farmers. Of these, the Technology Acceptance Model (TAM) was the most commonly applied (18.8%), followed by the Unified Theory of Acceptance and Use of Technology (UTAUT) (13.2 %) in the original or extended version. 22.6% of studies applied other theories, as in Table 2. Both developed and developing country studies used similar theories to assess the adoption of MPTs among farmers.

[Table 2]

The methodological quality of studies on farmer MPT adoption

Nearly half (41.5%) of the studies in this systematic review were rated as having "medium quality," 24.5% were ranked as "low quality, and only 34% were considered to be of "high quality." Generally, the low quality of studies was attributable to various methodological constraints ranging from (1) poorly defined research problems, objectives, and research questions, (2) missing information on sampling strategy, sample size, representativeness, response rates, and potential sources of bias, (3) missing information on measurement of constructs and critical indicators, data analysis, (4) inadequate substantiation of research findings using data to (5) the use of unstandardized or un-pretested measurement tools to (see Table 5 and supplementary table2).

[Table 5]

3.2 Farmers' perception of different MPTs and their associated usage

Farmers' perceptions regarding various MPTs were examined by 8% of the studies. Farmers rated phone features or apps related to herd management and crop protection as extremely useful. Regarding herd management, Michels, Bonke, and Musshoff (2019) reported that farmers found features facilitating reproduction management, feeding and milking control, data gathering, and animal health as the most useful. For crop protection, farmers considered apps that provide weather information, enable pest scouting and infestation forecast, facilitate making a product choice and documentation, and offer

recommendations to fertilizer quantities to be highly relevant (Michels, Bonke, & Musshoff, 2020). Similarly, (S. P. Thar et al., 2021) found that 85% of the farmers in their study said the agricultural apps they had used were useful. Regarding their information preferences, farmers attached high relative importance to information on crop production technologies, diseases and pests, weather forecasts, market prices, agricultural inputs, and disaster early warnings such as floods (Michels, Bonke, et al., 2020; S. P. Thar et al., 2021). Furthermore, farmers valued extension advice and information about their social relations (Rahman & Fadol, 2013; Siwel Yohakim Nyamba & Mlozi, 2012).

Related to MPT usage, farmers reported utilizing their MPTs for both work-related and non-work-related purposes. However, the review revealed differences in the types of MPTs and the purposes for which farmers used MPTs between developed and developing countries. While farmers in developed countries often utilized more complex apps that required the internet to search for information, market their products, and keep records, farmers in developing regions often used basic phone features like calling and SMS apps. Furthermore, the farmers in developing countries primarily utilize their mobile phones to maintain social relations among families and friends and seldom for acquiring agricultural information.

3.3 Types of variables

All extracted variables were grouped as either descriptive, latent, or dependent variables based on Kamrath et al. (2019). Within the context of this systematic review, the dependent variable is farmers' MPT adoption. It was operationalized using several adoption indicators, for instance, behavioral intention, attitude, and perception. Explaining farmers' MPT adoption variation is of great research interest. Often such variation is explained by independent (latent) variables, otherwise conceptualized as predictors or antecedents (Hair, Black, Babin, & Anderson, 2019; Leary, 2012). The first category of farmers' MPT adoption predictors featured in the reviewed studies includes latent variables. For example, perceived ease of use, trust, social influence, and perceived behavioral control were described using the constructs of various well-established theories, including UTAUT and TAM. The second factors influencing the adoption of MPTs among farmers, known as descriptive variables, relate to farmers' and farm characteristics and include gender, marital status, age, and income (Kamrath et al., 2019). Some variables were assigned to more than one group based on how they were examined in the studies. For example, constraints, knowledge, and mobile phone ownership were considered dependent and descriptive, while attitude and intention qualified as dependent and latent variables. Thus, these variables' percentages vary based on the total number of studies reporting them in each category.

Figure 2 summarizes the main categories and percentages of variables extracted.

[Figure 2]

3.4 Variation in the measurement of MPT adoption

The included studies evaluated similar MPT adoption indicators, albeit with different wordings, for instance, rate of use or extent of use. In total, twelve indicators of adoption were reported across the various studies. These indicators were farmers' generic use of MPTs (30%), Behavioral intention (21%), mobile phone ownership (32%), attitude towards MPT usage (11%), adoption (9%), frequency of use (9%), constraints to adoption (9%), use intensity (8%), perception (8%), willingness to adopt (9%), willingness to pay (2%), and knowledge (2%). Only one study assessed both the use and nonuse of MPTs among farmers (Krell et al., 2020).

Although similar variables were assessed, studies showed significant heterogeneity in measuring indicators. Of the eleven studies that assessed behavioral intention, six applied five-point Likert scales, two applied seven-point Likert scales, two measured intention as a binary variable eliciting yes or no responses, and one did not specify how adoption intention was measured. Adoption was measured using a five-point Likert scale (n=1) and as a dummy variable (n=4). Similarly, constraints were assessed as a dummy variable (n=2) and using four-point Likert scales (n=1). Attitude was measured using five-point (n=5) and four-point (n=1) Likert scales. Use of MPT was measured as a discrete choice variable (n=8), the number of phone

transactions made (n=1), using Likert scales (n=5), and the number of sim cards owned (n=1). Use intensity was measured using three-point (n=1) and five-point (n=2) Likert scales and as the number of phone activities carried out (n=2). Frequency of use was assessed using five (n=1) and six-point Likert scales and as a discrete choice variable (n=2).

Further heterogeneity was observed in the wording and number of items per construct among the studies utilizing Likert scales. For example, Landmann, Lagerkvist, and Otter (2021) and Mwalupaso et al. (2019) measured behavioral intention to use MPT using two items; Beza et al. (2018) and Molina-Maturano et al. (2021) used three items while Omar, Yap, Ho, and Keling (2021) and Victor et al. (2021) used five items (see Table 3).

[Table 3]

3.5 Determinants of MPT adoption among farmers

Based on past reviews (Olum, Gellynck, Juvinal, Ongeng, & De Steur, 2019; Oluwamayokun , Anoma, & Ammar, 2022), five categories of factors driving farmers' MPT adoption emerged from the reviewed studies, as described in the following paragraphs. Table 4 summarizes the significant determinants of farmers' MPT adoption.

Socio-demographic factors refer to farm, farmer, or household characteristics (Olum et al., 2019). Among these factors, education was the most examined (66%), followed by age (62%), gender (47%), income (n=21), farm size (n=19), marital status (n=12), farming experience (n=10), and household size (n=8). While education was found to influence MPT adoption positively in 94% of the 35 studies that examined the effect of education, the remaining 6% reported its insignificant influence on farmer MPT. The reported effect of the rest of the sociodemographic factors on farmer MPT adoption remained mixed and inconclusive (see Table 4).

[Table 4]

Technological and mobile phone-use-related factors.

Perceived advantage was examined by 23% of studies, followed by perceived usefulness (17%), perceived ease of use (13.2%), performance expectancy (8%), effort expectancy (6%), and perceived cost (6%). Of these technological factors, performance expectancy, effort expectancy, and perceived advantage positively influenced MPT adoption among farmers. However, the findings regarding the influence of perceived usefulness, perceived cost, and perceived ease of use varied among studies, with both positive and negative effects being reported.

Among the mobile-use-related factors assessed, mobile phone ownership and duration of ownership (32%), experience (9%), the number of mobile phones owned (9%), and farmer's skills and aptitude (n=8%) were all found to have a positive effect on the adoption and use of MPT among farmers.

Psychological and behavioral factors.

Several factors dealing with farmers' psychological state and subjective evaluation of MPTs featured in the reviewed studies. They included subjective norm (23%), personal innovativeness (21%), attitude (17%), intention (9%), trust (6%), perceived reliability of mobile phone services (6%), emotions (4%), perception (4%), information seeking behavior (2%), habit (2%), self-efficacy (2%) and behavioral control (2%). These factors were reported to positively and significantly influence farmers' MPT adoption.

Biophysical factors such as operational, on-farm natural, and physical characteristics influence farmers' adoption decisions (Olum et al., 2019). The influence of diversification (8%), land ownership/tenancy (6%), farm type (8%), farmers' total landholding (4%), and area under cultivation (4%) were assessed. While diversification and land ownership were found to have insignificant influences on farmers' MPT adoption, the total landholding and farm type were reported to have negative and positive impacts, respectively. The area under cultivation yielded mixed effects on MPT adoption.

Constraints and institutional factors

Nearly all studies (85%) reported on the constraints and institutional factors determining farmers' adoption and usage of MPTs. Of these, knowledge of Apps (6%), information awareness (4%), participation in credit (4%) and training programs (4%), type, quality, and complexity of agricultural information (6%), assets (4%), farmers' network capacity, and facilitating conditions influenced farmers' MPT adoption positively. In contrast, distance from the market center or nearest town (11%), poor quality mobile phones (battery), poor internet and mobile network connectivity (9%), high cost of internet services (6%), lack of digital knowledge and skills (40%), lack of interest (2%), and language barrier (28%) were found to have negative effects on farmers' MPT adoption. The influence of group membership (15%) and access to electricity (11%) remained mixed and inconclusive. In addition to the above-mentioned factors, some farmers reported health-related issues such as hearing problems contributing to the failure to use mobile technologies.

Understanding that these constraints vary between developed and developing countries is essential. For example, network failure, language barrier, poverty, high prices of MPTs, limited digital aptitude and skills, lack of electricity, and limited access to mobile phone accessories were critical for MPT adoption in developing countries. However, the high cost of internet services and computer literacy were more crucial for developed countries, while the rest of the factors overlapped between developed and developing country contexts.

4 Discussion

The 53 articles included in this systematic review comprise an active and growing body of research on farmers' adoption of MPTs, highlighting the main determinants, constraints methods and measures of adoption, farmers' perception of the different MPTs, and the methodological quality of studies in this field. These are discussed in the following sub-sections.

4.1 Distribution of studies

This systematic review shows a significant focus of farmers' MPT adoption studies in countries on the African and Asian continents, mainly Nigeria, Ghana, Tanzania, Ethiopia, and India. This result reflects those of Olum et al. (2019), who, in their systematic review, also found that most studies on farmers' adoption of agricultural innovations targeted developing countries. This focus on developing countries may be due to the United Nation's 2030 agenda for Sustainable development call for actions to ameliorate the technological capabilities of all industrial sectors, including agriculture, especially in developing countries characterized mainly by inequality and low adoption of innovation (Stafford-Smith et al., 2017). As (Pangaribowo & Gerber, 2016), new platform technologies, including MPTs, provide avenues for combating various risks and uncertainties often faced by farmers before, during, and after agricultural production, consequently boosting their production. Such avenues include providing market and price information, knowledge sharing, crop insurance, improved market access, and decision-making tools, including what and when to grow. Thus, redirecting technological innovations from developed to developing countries could promote food security and nutrition by counteracting the complex and evolving challenges of the global food system (Juma & Yee-cheong, 2005), attesting to sustainable development goal (SDG) 2 on zero hunger.

The reviewed body of literature points to a growing interest among researchers and development practitioners in this particular topic, as evidenced by the yearly increase in publications on MPT adoption among farmers. Moreover, it affirms the progressive recognition of the role of MPT in enhancing agricultural productivity and contributing to sustainable development (Mugambiwa & Tirivangasi, 2017).

4.2 ***Heterogeneity in the measurement of farmers' MPT adoption indicators.***

As noted by Clark and Watson (2019), the quality of real-world decisions made based on psychological measurements depends mainly on the construct validity of the measures. Although common indicators of MPT adoption were reported across the reviewed studies, significant variation was observed in the measurement of these indicators or constructs in terms of the scales used, the number and wording of items, and the measure employed. The observed heterogeneity in measures of MPT adoption might significantly compromise the validity of the research instruments used to collect data. Therefore, such discrepancies must be considered when comparing studies. From a practical point of view, we suggest (1) caution when interpreting findings from such studies, (2) harmonization or standardization of adoption indicators and their measures as well as instruments, and (3) future research might be needed to conduct studies on the impact of the methodological differences in the assessment of MPT adoption to gain insight on the extent to which the call for caution is warranted.

In accordance with past literature, the current study revealed a sub-optimal use of behavioral theories and models in the design of studies seeking to understand farmers' adoption of MPT. (Michie, Johnston, Francis, Hardeman, & Eccles, 2008) observed that choosing appropriate theories is complex and often results in most interventions seeking to change behavior being devised without reference to theory (Davies, Walker, & Grimshaw, 2010; Prestwich et al., 2014). Previous research, however, underscores the relevance of solid theoretical foundations when designing behavioral change programs to improve their success and allow synergistic effects (Dombrowski et al., 2012).

This review also found that studies do not employ a typical "standardized" or identical theory or model to examine MPT adoption and usage. The application of diverse models makes comparing studies difficult and prevents quantitative meta-analysis. While it may be hard to avoid heterogeneity in theories (and methods), we suggest that studies might at least pay more attention to theoretical underpinnings while considering the specificities of the different contexts to see which theoretical model fits best

4.3 The role of determinants of MPT adoption

Socio-demographic factors. Most studies (94%) reported the positive influence of education on farmers' decisions to adopt MPTs. This finding is consistent with that of Mittal and Mehar (2016), who found a positive relationship between the use of mobile phones and farmers' level of education. Several authors posit that knowledge and analytical capacity are prerequisites for adopting innovations in agricultural systems (Olum et al., 2019; S. P. Thar et al., 2021). While people with little or no education can perform basic phone functions like voice calling, operating smartphones with several features require a specific skillset (Islam & Gronlund, 2011). The significant role of education underscores the need for governmental, non-governmental, and private sector agencies to provide relevant training and technical education for farmers through capacity-building programs to increase their awareness of using MPTs for agriculture. Girma and Kelil (2021) suggest awareness campaigns organized by telecommunication companies, mobile app developers, and the agricultural department as possible avenues to advance adult education and enhance farmers' competence through tailored training on the use of mobile applications (Abdullahi, Oladele, & Akinyemi, 2021)

The somewhat surprising positive effect of age on MPT adoption reported in some studies could be attributed to the farming experience through which farmers realize the benefits and need for innovation (Kabirigi, Sekabira, Sun, & Hermans, 2022b). Consistent with extant literature, younger farmers in the included studies showed more willingness to adopt mobile agricultural apps or use their phones for agricultural purposes. Seemingly, younger farmers anticipate benefits from utilizing innovation in the long term. Therefore, they tend to be more radical and innovative concerning new technologies (Chellappan & Sudha, 2015). (Kabirigi et al., 2022b) recommend youth involvement through strategies that enable easy access to smartphones for successful agricultural digitalization and possible transfer of digital skills to the older farmers through the younger ones.

Our review highlighted a gender divide in MPT adoption among farmers in developed and developing countries. Similarly, past studies point to male dominance in technology adoption (Obisesan, 2014), suggesting differential adoption rates between men and women (Aduwo et al., 2019). This gender difference in adoption rates, especially in developing countries, might be attributed to gender inequality in the access to information, physical and financial resources, and societal norms (Radovic-Markovic, Kabir, & Jovicic, 2020; Theis, Lefore, Meinzen-Dick, & Bryan, 2018). The prevalent gender gap in farmer adoption of MPT necessitates relevant stakeholders, including developers and researchers, to understand the factors associated with these differences. Understanding such factors would increase the uptake of MPTs among farmers, ensure the positive impacts of MPT are sustained, and contribute to SDG 5 on gender equality.

Technological and mobile phone-use-related factors. The growing popularity of mobile phones is partly due to their relative ease of use. The user's perception regarding the ease of use of a given technology determines the technology's adoption (Kabbiri et al., 2018). James (2009) notes that for users to accept and use MPTs, they must find their operations easy to learn. Similarly, performance expectancy, effort expectancy, and perceived advantage were reported to positively influence MPT adoption among farmers. Therefore, as also suggested by Kabbiri et al. (2018), it is vital for all actors within the mobile phone industry and the agricultural sector to consider farmers' perceptions relating to ease of use. For instance, application developers should consider designing mobile applications that are easy to learn and use for low-literacy farmers and suited to the farmers' context.

Perceived usefulness is the subjective expectation of an individual that using new technology will enhance their performance (Davis, 1993), and past studies allude to its positive effect on technology adoption (Venkatesh & Davis, 1996; Venkatesh & Morris, 2000). Similarly, perceived usefulness positively influenced farmers' MPTs adoption, generally among the reviewed studies. Most farmers believed that using a mobile phone could boost their agricultural performance. Therefore, farmer-oriented governmental and non-governmental agencies may find it valuable to collaborate with mobile phone companies to develop MPTs and applications that target farmers' specific needs, and enhance their daily operations. When such applications are considered relevant by the farming communities, their adoption and agricultural productivity will increase.

According to Omar et al. (2021), the perceived cost related to MPTs are severalfold, namely; initial cost (e.g., acquisition of MPT), usage cost (e.g., buying credit, data, and financial transaction fees), maintenance cost (e.g., app and internet subscription, repair, and accessories replacement); cost of building relationships with other stakeholders along the agricultural value chain and the costs concomitant with the time and effort taken to collect data and assess options to decision-making. Such costs were found to influence farmers' MPT adoption negatively generally. Therefore, efforts directed towards subsidizing the cost of MPTs by the government and telecom companies could facilitate MPT adoption among farmers, especially those in low-income countries. In line with the effect of costs, some exceptions were reported. For instance, Omar et al. (2021) found that farmers in Sarawak adopted a gain-oriented approach that motivated them to adopt apps in expectation of higher values regardless of the potential costs. Additionally, it is presumed that the MPT usage experience shapes farmers' perceptions of benefits and costs. This finding highlights the possible role of training and sensitization in creating awareness among farmers of the benefits of MPT.

The triple hurdle approach, proposed by (Asravor et al., 2021), postulates the ownership decision as the first critical hurdle toward MPT usage that generates the willingness and ability to explore MPT products and their functionalities. Mobile phone ownership and ownership duration were found to positively influence farmers' decisions to use MPTs in agriculture. Extended ownership periods probably allow farmers to witness firsthand the economic gains and cultural transformations associated with MPTs (Asravor et al., 2021). That mobile phone ownership increases usage by farmers is possibly a result of increased product knowledge (Osadebamwen & Ele, 2015). Thus, mobile phone developers, extension

workers, and development practitioners might consider it worthwhile to influence the decision to own a mobile phone by addressing constraints such as costs and creating awareness of the benefits of MPTs.

Psychological and behavioral factors.

The studies reviewed reported a positive effect of social influence on farmers' intention to adopt MPTs, and previous reviews on technology adoption support this finding (Kamrath et al., 2019; Olum et al., 2019). Most farmers would adopt MPTs and other innovations if their family members or other farmers in their networks approved of and used them. Furthermore, subjective norms influenced people's intention to adopt digital financial services and M-payment in a collective society positively (Hussain, Mollik, Johns, & Rahman, 2019; Martins, Oliveira, & Popovic, 2014). Landmann et al. (2021) recommend using village-wide field demonstrations to enhance MPT usage rates since farmers may need initial guidance when introducing MPTs. Furthermore, field demonstrations might provide a great way to encourage village-wide adoption of MPTs because farmers value the judgment of their networks. Thus, programs seeking to promote MPT use in agriculture might target cooperative groups or farmer-based organizations as entry points to gain support for new MPT innovations and encourage widespread adoption. (Asravor et al., 2021) noted that such groups enhance farmers' knowledge, awareness, and capacity and contribute to the decision to use MPTs.

Self-efficacy, a person's belief in their ability to exercise control over specific tasks (Bandura, 1977), was found to influence farmers' adoption intentions regarding MPT positively. This finding underscores the role of individual optimism in one's ability and motivation for MPT usage (Landmann et al., 2021). It suggests the need for tailored training and skilling programs that meet farmers' mobile use needs and boost their confidence.

Constraints and institutional factors. The transfer of innovations and technology uptake require solid support from financial providers, private sector-led, and government institutions (Olum et al., 2019). Farmers' network capacity influenced MPT adoption decisions positively in both developed (e.g., Italy) and developing countries. Thus, institutional approaches could target farmer associations when introducing new MPTs. For countries in developing regions, for example, Uganda, government policies could be directed towards reviving and supporting farmer cooperatives to facilitate the uptake of technologies, including MPTs. Access to credit also had a positive influence on MPT adoption. Thus, micro-finance institutions and governments could consider providing financial support through subsidies or soft loans to facilitate farmers' uptake of MPT (Girma & Kelil, 2021; Sikundla et al., 2018).

Furthermore, information awareness positively affected farmers' intention and adoption of MPTs. Mwangi and Kariuki (2015) posit information awareness as a necessary precursor to farmers' adoption of technology. Yet, information asymmetries remain a significant obstacle to technology adoption, predominantly in developing countries (Nakasone et al., 2014). Without prior knowledge of available MPTs, many farmers fail to implement and benefit from them, despite having positive intentions (Misaki et al., 2018). Cognizant of the possibility that poorly packaged information can lower MPT adoption (Kabunga, Dubois, & Qaim, 2012; Mwangi & Kariuki, 2015), the information provided to farmers concerning or through MPTs must be timely, accurate, relevant, consistent, and from a trusted source to promote adoption (Olum et al., 2019).

According to Anjum (2015), incorporating extant social and psychological barriers in the design stage might promote farmers' MPT adoption. Our study highlighted the critical role of language barrier in limiting access and utilization of MPTs by local farmers, especially in countries where English is not an official language. Using foreign languages in a local context might lead to misinterpretation (Asenso-Okyere & Mekonnen, 2012) and misuse of the information provided. Thus, ethical and language consideration is critical to MPT companies in the initial design stage when developing mobile applications and content. Misaki et al. (2018) suggest incorporating local languages relevant to the cultural context in the MPT design process to promote the adoption and scalability of mobile phone use in agriculture. From a managerial perspective, it may be cumbersome and even unrealistic to perhaps translate MPTs into all local languages,

especially in an environment of many dialects typical of many developing countries in Africa and Asia. However, the benefits of translation still outweigh its downsides. Therefore, we suggest that the translation of MPT services and features into local languages could target leading (commonly) spoken languages for a start. Thus, even though some minority groups might be left out, the transmission of information, adoption, and utilization of MPTs could be significantly improved among the target populations.

Venkatesh et al. (2003) define the extent to which a person believes that organizational and technical structures are in place to support the use of a system as facilitating conditions. They constitute perceived environmental barriers or enablers that influence an individual's perception of the ease or difficulty of performing a task (Teo, 2010). According to Owusu, Yankson & Frimpong (2017), facilitating conditions such as resource availability, reliable electricity, good internet, mobile networks, skills, and technical infrastructure could play a key role in MPT adoption among farmers. This finding has important implications for developing countries often plagued by inadequate infrastructure, including epileptic power supplies, poor internet and network connectivity, and weak broadband signals (Falola & Adewumi, 2011; Ogunniyi & Ojebuyi, 2016). It raises intriguing questions regarding the nature and extent of support different stakeholders can provide to address such challenges. We propose that governments and non-governmental organizations orient their development efforts towards upgrading rural infrastructure to facilitate farmers' MPT adoption for agricultural use (Owusu, Yankson, & Frimpong, 2017). Moreover, there is a need for policy reforms that deliberately provide an enabling environment to support mobile companies and farmers, thus encouraging MPT adoption and usage (Narine, Harder, & Roberts, 2019). Such reforms require effective public-private partnership and collaboration by stakeholders within the agricultural and mobile industry to implement appropriate policies (Mgbenka, Mbah, & Ezeano, 2015).

5 Strengths and Limitations of the study

Our study has its strengths in (1) using the well-established PRISMA guidelines and a review protocol to conduct a systematic literature review of farmers' adoption of MPT and ensure that the process can be replicated (2) inclusion of studies from both developing and developed countries perspective, and (3) the assessment of the methodological quality of included studies using the Mixed Method Appraisal Tool (4) enhancing understanding of the drivers of farmers' adoption of MPTs, measures, theories, and adoption indicators, and provides direction for future research.

Despite the robustness of our review, however, we acknowledge some limitations. First, we restricted our search to the web of science electronic database. Although this is not unprecedented in our field of research (see Inwood & Dale, 2019; Kamrath et al., 2019; Olum et al., 2019) and was supplemented by citation and reference list search, we recognize that some relevant studies not indexed by the Web of Science could have been missed in the literature search. Moreover, we considered only full-text articles published in English and could have left articles published in other languages and not electronically available. Although the relatively small sample size of included studies indicates that this growing research field is in its nascent stages, we recommend carefully interpreting our findings.

Secondly, the heterogeneity of MPT outcome measures and variables reported across the included studies due to the lack of standardized tools, methods, and reporting made it impossible to conduct a reliable statistical meta-analysis which would have otherwise enabled the calculation of the effect sizes of various determinants of MPT adoption (Wely, 2014).

Thirdly, only 34% of the included studies were ranked as "high quality, with nearly 50% of studies not providing details on how various constructs and indicators of MPT adoption were measured. Moreover, only reporting significant relationships with missing information on effect sizes constitutes publication bias (Hirschauer et al., 2016). Petticrew and Roberts (2006) noted that such targeted reporting complicates the comparison of significant to non-significant assessments. Therefore, interpretation of our findings should

factor in this publication bias. As Kamrath et al. (2019) suggested, researchers should aim to enhance transparency in research by providing information on the concepts and constructs they measure.

6 Conclusions

The current work was designed to systematically examine farmers' MPT adoption studies and appraise their methodological quality. Specifically, it sought to (a) analyze and synthesize the key determinants and constraints of MPT adoption among farmers; (b) evaluate the various measures, methods, and theories employed by studies to understand MPT adoption; (c) assess farmers' perception regarding different MPTs and their associated usage, (d)appraise study quality and (e) identify gaps and areas for future research regarding MPT adoption among farmers.

Our systematic review highlights a rapidly growing body of MPT adoption literature, especially targeting developing countries. However, these studies oriented towards MPT usage in developing countries target more basic phones and technologies such as SMS, unlike the developed country studies focusing on more advanced technologies exploring the usage of smartphones and applications.

The articles included in the review point to the positive role of factors such as perceived ease of use, perceived usefulness, farmers' innovativeness, mastery goal orientation, perceived advantage, education, farmer's network capacity, credit access, mobile phone ownership, and ownership duration on the decision to adopt MPTs. The importance of the determinants of farmer MPT adoption was shown to differ between regions. For instance, education, age, family size, and constraints such as the high cost associated with MPT acquisition and usage, language barrier, and inadequate infrastructure were identified as the main determinants of MPT adoption among farmers in developing countries. However, Computer literacy, weather variability, and price volatility were recognized as the primary challenges hindering MPT adoption among farmers in developed countries (e.g., Germany). Understanding these contextual differences might be beneficial in need-specific tailoring of solutions to promote MPT among farmers in developed and developing countries.

All of the studies examined were cross-sectional and mainly applied quantitative descriptive methods, followed by the mixed methods approaches, then qualitative methods.

The reviewed articles featured a variety of MPT adoption indicators and outcome measures ranging from mobile phone ownership, intention to use, generic MPT usage, adoption, perception, attitude, knowledge intensity, frequency of use, constraints, willingness to pay, and willingness to adopt. Similarly, the included studies varied significantly in measuring indicators, with some soliciting yes/no responses and others using Likert scales ranging from 3 to 7-point scales, revealing heterogeneity in the measurement of adoption among farmers. Heterogeneity was also found in the number and wording of items used to measure the same construct of a given theory to examine MPT adoption among farmers.

The generally low quality of the studies included in this review suggests a dire need to improve study designs, methods, and measurements to capture evidence on farmers' MPT adoption more satisfactorily. Similar to the suggestion by Parikh et al. (2022), enhancing the quality of research and filling the knowledge gap will be crucial to influencing MPT adoption among farmers and transforming agricultural productivity. We, therefore, propose the following

Methodological recommendations*;*

- Complement the cross-sectional designs with longitudinal studies to predict MPT adoption behavior and beliefs over time (Omar et al., 2021).
- Future studies should consider transparently stating their methodology, including sampling methods, data collection and analysis, measurement of different variables, and publicly availing their research tools (Diaz et al., 2021).
- Develop and disseminate pre-tested and validated standardized tools to facilitate harmonized data collection on mobile phone technologies across diverse farmer profiles and settings.

- As also proposed by Parikh et al. (2022), augment quantitative and qualitative methods for a more holistic assessment of the status of MPT adoption.
- Future studies should identify straightforward research questions and objectives, use appropriate methodologies and validated tools, and base interpretation of results on the data obtained.
- Farmers' preferences for different MPTs and applications should be further investigated using a choice experimental design.
- Address the lack of theoretical underpinnings in MPT adoption, and if possible, consider the context in which these theories could best be applied.

Future research recommendations

- Extend the scope of MPT adoption research to evaluate both users and non-users in a single study design, to compare similarities and differences in perceptions, and the reason for non-adoption (Michels, Bonke, & Musshoff, 2019).
- Furthermore, studies should investigate why most farmers do not use mobile agricultural apps despite perceiving them as applicable (Michels et al., 2020). Relatedly, identify the work-specific barriers preventing the growing number of farmers who already own a smartphone from using it for agricultural purposes (Landmann, Lagerkvist, and Otter, 2020).
- Examine farmers' perceptions regarding the impacts of MPT adoption on their social networks and agricultural outcomes.
- Investigate the possibility and effectiveness of mobile data collection, especially among smallholders.
- More studies are still needed to compare and contrast the inconclusive effects of various determinants on MPT adoption.
- Measure MPT adoption patterns among farmers using established theories, such as diffusion of innovation theory (Michels, Bonke, & Musshoff, 2019).
- Extend the scope of studies examining farmers' willingness - to - Pay for agricultural applications beyond soliciting yes/No responses and assess the extent of their desire to understand the value farmers attribute to mobile applications (Bonke et al., 2018)
- Examine the relationship between farmers' identity and their engagement with agricultural (smartphone) applications (Kenny & Regan, 2021).
- Direct efforts towards understanding farmers' lack of trust in agricultural Apps and MPTs.
- Assess the apparently strong link between farmer network participation and farm advisor use with the higher level of agricultural app adoption (Schulz et al., 2021).
- More research is required to integrate MPTs with traditional farmer extension and training methods.
- Assess the role of government in farmers' adoption of MPTs and related services.
- Examine how the importance of various determinants on farmer MPT adoption change over time or in context
- Conduct studies on the impact of the methodological differences in assessing MPT adoption.
- Extend the scope of MPT adoption studies beyond the farmer level, and include traders, suppliers, distributors, government organizations, and respective boards of agriculture in one study design to provide a different yet holistic perspective on the adoption of MPTs (Nabhani et al., 2016)

Policy and development recommendations

- Heed to the intersection between gender and MPT adoption among farmers when designing or implementing ICT programs (Molina-Maturano et al., 2021; Owusu, Yankson, & Frimpong, 2017)
- Direct efforts towards addressing farmers' lack of trust in agricultural Apps and MPTs.
- Consider social dynamics within farming communities, such as sharing and borrowing phones, when designing MPT-related policies or programs.

- Orient efforts towards educating farmers on the benefits of mobile apps and offering tailored training to enhance their competence in mobile phone usage (Abdullahi, Oladele, & Akinyemi, 2021; Nabhani et al., 2016; Okoroji, Lees & Lucock, 2021)
- Enhance farmers' positive intention toward MPT usage through subsidization of costs associated with MPT adoption and use (Nyamba & Mlozi, 2012; Okoroji, Lees & Lucock, 2021)
- To unlock the full potential of MPTs in developing countries, consider interventions like rural electrification and solar phone charging stations (Obong, Mugonola, & Paul Phillips, 2018)
- Incorporate mobile phones in the traditional extension systems, and consider providing information to farming households via MPTs.
- Focus on implementing public sensitization to create awareness regarding various MPTs.
- Make MPT services more customizable to the local context, and allow for translation into local languages to facilitate use by low-literacy farmers (Kabirigi et al., 2022).
- Target the youth when designing and introducing new MPT innovations.
- Formative evaluation is necessary to ensure farmers' feedback is factored into the rollout of MPT programs
- Pay attention to the social differences between developed and developing countries during MPT designs, implementation, and further research. Similarly, create relevant and quality content when designing MPTs for farmers.
- To boost adoption and support for the use of MPTs, mobile app developers and public and private sector players may consider co-designing applications and mobile-related programs with farmers.
- Together with the government, mobile phone developers could consider subsidizing the internet, airtime, and other services to facilitate farmers' use of MPTs in agriculture (Sikundla, Mushunje, & Akinyemi, 2018). As a further step, telecommunication companies should extend and strengthen their network coverage and enhance the quality of their products to allow MPT adoption among farmers.

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References

Abdullahi, K. A., Oladele, O. I., & Akinyemi, M. (2021). Attitude, knowledge and constraints associated with the use of mobile phone applications by farmers in North West Nigeria. *Journal of Agriculture and Food Research, 6*. doi:10.1016/j.jafr.2021.100212

Abdullahi, K. A., Oladele, O. I., & Yusuf, O. J. (2019). Use of Mobile Phone Applications by Farmers in North West Nigeria. *Journal of Agricultural Extension, 23*(3), 182-195. doi:10.4314/jae.v23i3.16

Aduwo, O. E., Aransiola, J. O., Ikuteyijo, L. O., Alao, O. T., Deji, O. F., Ayinde, J. O., . . . Oyedele, D. J. (2019). Gender differences in agricultural technology adoption in developing countries: a systematic review. *Acta Horticulturae*(1238), 227-238. doi:10.17660/ActaHortic.2019.1238.24

Aker, J. C. (2011). Dial "A" for agriculture: a review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics, 42*(6), 631-647. doi:10.1111/j.1574-0862.2011.00545.x

Aker, J. C., Ghosh, I., & Burrell, J. (2016). The promise (and pitfalls) of ICT for agriculture initiatives. *Agricultural Economics, 47*, 35-48. doi:10.1111/agec.12301

Alam, G. M. M., Alam, K., Mushtaq, S., Khatun, M. N., & Mamun, M. S. A. K. (2018). Influence of socio-demographic factors on mobile phone adoption in rural Bangladesh: Policy implications. *Information Development, 35*(5), 739-748. doi:10.1177/0266666918792040

762 Aldosari, F. O., Al-Sakran, M. S., Alkhubizi, H. F. N., Al-Zaidi, A. A., Baig, M. B., Muddassir, M., Mubushar,
763 M. (2017). Use of Cell Phones by the Farmers as an Extension Tool to Practice Sustainable
764 Agriculture and Achieve Food Security in the Kingdom of Saudi Arabia. *Journal of Experimental*
765 *Biology and Agricultural Sciences, 5*, S91-S98. doi:10.18006/2017.5(Spl-1-SAFSAW).S91.S98
766 Animashaun, J. O., Fakayode, S. B., Idris, K. A., & Adedokun, K. F. (2014). Patterns and Drivers of Mobile
767 Telephony for Sustainable Livelihood among Farming Households in Kwara State, Nigeria. *Journal*
768 *of Agricultural informatics*.
769 Anjum, R. (2015). *Design of mobile phone services to support farmers in developing countries.* University
770 of Eastern Finland,
771 Aricat, R. G., & Ling, R. (2017). Collective appropriation and cooperative uses of mobile telephony among
772 Burmese fishers. *Information Development, 34*(5), 433-446. doi:10.1177/0266666917719116
773 Asenso-Okyere, K., & Mekonnen, D. A. (2012). *The Importance of ICTs in the provision of Information for*
774 *Improving Agricultural Productivity and Rural Incomes in Africa*. Retrieved from
775 Asravor, R. K., Boakye, A., & Essuman, J. (2021). Adoption and intensity of use of mobile money among
776 smallholder farmers in rural Ghana. *Information Development, 38*(2), 204-217.
777 doi:10.1177/0266666921999089
778 Baardewijk, M. v. (2017). The impact of mobile phone use and IKSL's audio messages on the asset base of
779 poor farmers in Lucknow, India. *The Electronic Journal of Information Systems in Developing*
780 *Countries*.
781 Bandura, A. (1977). Self-efficacy: toward a unifying theory of behavioral change. *Psychological Review,*
782 *84*(2), 191-215. doi:10.1037//0033-295x.84.2.191
783 Baumüller, H. (2017). The Little We Know: An Exploratory Literature Review on the Utility of Mobile Phone-
784 Enabled Services for Smallholder Farmers. *Journal of International Development, 30*(1), 134-154.
785 doi:10.1002/jid.3314
786 Beza, E., Reidsma, P., Poortvliet, P. M., Belay, M. M., Bijen, B. S., & Kooistra, L. (2018). Exploring farmers'
787 intentions to adopt mobile Short Message Service (SMS) for citizen science in agriculture.
788 *Computers and Electronics in Agriculture, 151*, 295-310. doi:10.1016/j.compag.2018.06.015
789 Bonke, V., Fecke, W., Michels, M., & Musshoff, O. (2018). Willingness to pay for smartphone apps
790 facilitating sustainable crop protection. *Agronomy for Sustainable Development, 38*(5). doi:ARTN
791 5110.1007/s13593-018-0532-4
792 Butt, B. (2015). Herding by Mobile Phone: Technology, Social Networks and the "Transformation" of
793 Pastoral Herding in East Africa. *Human Ecology, 43*(1), 1-14. doi:10.1007/s10745-014-9710-4
794 Chellappan, S., & Sudha, R. (2015). Investment, adoption, attitude and extent of participation of farmers
795 in soil conservation projects in the Western Ghats of India. *International Journal of Social*
796 *Economics, 42*(3), 251-275. doi:10.1108/ijse-10-2013-0219
797 Clark, L. A., & Watson, D. (2019). Constructing validity: New developments in creating objective measuring
798 instruments. *Psychological assessment, 31*(12), 1412-1427. doi:10.1037/pas0000626
799 Crowe, M., & Sheppard, L. (2011). A review of critical appraisal tools show they lack rigor: Alternative tool
800 structure is proposed. *Journal of clinical epidemiology, 64*(1), 79-89.
801 doi:10.1016/j.jclinepi.2010.02.008
802 Davies, P., Walker, A. E., & Grimshaw, J. M. (2010). A systematic review of the use of theory in the design
803 of guideline dissemination and implementation strategies and interpretation of the results of
804 rigorous evaluations. *Implementation science*.
805 Davis, F. D. (1993). User acceptance of information technology: system characteristics, user perceptions
806 and behavioral impacts. *International Journal of Man-Machine Studies*
807 Diaz, A. C., Sasaki, N., Tsusaka, T. W., & Szabo, S. (2021). Factors affecting farmers' willingness to adopt a
808 mobile app in the marketing of bamboo products. *Resources, Conservation & Recycling Advances,*
809 *11*. doi:10.1016/j.rcradv.2021.200056

Dombrowski, S. U., Sniehotta, F. F., Avenell, A., Johnston, M., MacLennan, G., & Araújo-Soares, V. (2012). Identifying active ingredients in complex behavioural interventions for obese adults with obesity-related co-morbidities or additional risk factors for co-morbidities: a systematic review. *Health psychology review, 6*(1), 7-32. doi:10.1080/17437199.2010.513298

Duncombe, R. (2015). Mobile Phones for Agricultural and Rural Development: A Literature Review and Suggestions for Future Research. *The European Journal of Development Research, 28*(2), 213-235. doi:10.1057/ejdr.2014.60

El Ayadi, A. M., Nalubwama, H., Barageine, J. K., Miller, S., Obore, S., Kakaire, O., . . . Byamugisha, J. (2020). Feasibility and acceptability of mobile phone data collection for longitudinal follow-up among patients treated for obstetric fistula in Uganda. *Health care for women international*, 1-15. doi:10.1080/07399332.2020.1825439

Ezeoha, A. E., Obi, A., Igwe, A., & Ezeruigbo, C. (2020). The mobile phone revolution, the Internet and rural electricity: What are the implications for food security in Africa? *Information Development, 36*(4), 603-622. doi:10.1177/0266666919884991

Falola, A., & Adewumi, M. O. (2011). Constraints to use of mobile telephony for agricultural production in Ondo State, Nigeria *Journal of research in forestry, wildlife and environment, 4*.

Filippini, R., Marescotti, M. E., Demartini, E., & Gaviglio, A. (2020). Social Networks as Drivers for Technology Adoption: A Study from a Rural Mountain Area in Italy. *Sustainability, 12*(22). doi:10.3390/su12229392

Folitse, B. Y., Manteaw, S. A., Dzandu, L. P., Obeng-Koranteng, G., & Bekoe, S. (2018). The determinants of mobile-phone usage among small-scale poultry farmers in Ghana. *Information Development, 35*(4), 564-574. doi:10.1177/0266666918772005

Girma, Y., & Kelil, A. (2021). Mobile phone and beef cattle marketing: The case of Girar Jarso district of Oromia region, Ethiopia. *Cogent Food & Agriculture, 7*(1). doi:10.1080/23311932.2021.1911032

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health information and libraries journal, 26*(2), 91-108. doi:10.1111/j.1471-1842.2009.00848.x

Hair, F. J., Black, C. W., Babin, J. B., & Anderson, E. R. (2019). *Multivariate Data Analysis* (8th Ed.): Annabel Ainscow.

Hannes, K., & Macaitis, K. (2012). A move to more systematic and transparent approaches in qualitative evidence synthesis: update on a review of published papers. *Qualitative Research, 12*(4), 402-442. doi:10.1177/1468794111432992

Hirschauer, N., Mußhoff, O., Grüner, S., Frey, U., Theesfeld, I., & Wagner, P. (2016). Die Interpretation des p-Wertes – Grundsätzliche Missverständnisse. *Jahrbücher für Nationalökonomie und Statistik, 236*(5). doi:10.1515/jbnst-2015-1030

Hoang, G. H. (2020). Adoption of Mobile Phone for Marketing of Cereals by Smallholder Farmers in Quang Dien District of Vietnam. *Journal of Agricultural Extension, 24*(1), 106-117. doi:10.4314/jae.v24i1.11

Hoang, H. G., & Drysdale, D. (2021). Factors affecting smallholder farmers' adoption of mobile phones for livestock and poultry marketing in Vietnam: implications for extension strategies. *Rural Extension and Innovation Systems Journal, 17*(1), 21-30. Retrieved from <Go toISI>://WOS:000635495800004

Hong, Q. N., Pierre Pluye, Sergi Fàbregues, Gillian Bartlett, Felicity Boardman, Margaret Cargo, Vedela, I. (2018). Mixed Methods Appraisal Tool (MMAT) Version 2018. In.

Hussain, M., Mollik, A., Johns, R., & Rahman, M. S. (2019). M-payment adoption for bottom of pyramid segment: an empirical investigation. *International Journal of Bank Marketing, 37*(1), 362-381. doi:10.1108/Ijbm-01-2018-0013

Inwood, S. E. E., & Dale, V. H. (2019). State of apps targeting management for sustainability of agricultural landscapes. A review. *Agronomy for Sustainable Development, 39*(1). doi:10.1007/s13593-018-0549-8

Islam, M. S., & Gronlund, A. (2011). Bangladesh calling: farmers' technology use practices as a driver for development. *Information Technology for Development, 17*(2), 95-111. doi:10.1080/02681102.2010.526093

James, J. (2009). Leapfrogging into mobile telephony: A measure for comparing country performance. *Technological Forecasting and Social Change*. doi:10.1016/j.techfore.2008.09.002

Juma, C., & Yee-cheong, L. (2005). *Innovation: applying knowledge in development, UN Millennium Project, Task Force on Science, Technology, and Innovation*.

Kabbiri, R., Dora, M., Kumar, V., Elepu, G., & Gellynck, X. (2018). Mobile phone adoption in agri-food sector: Are farmers in Sub-Saharan Africa connected? *Technological Forecasting and Social Change, 131*, 253-261. doi:10.1016/j.techfore.2017.12.010

Kabirigi, M., Sekabira, H., Sun, Z., & Hermans, F. (2022). The use of mobile phones and the heterogeneity of banana farmers in Rwanda. *Environment Development and Sustainability*. doi:10.1007/s10668-022-02268-9

Kabunga, N. S., Dubois, T., & Qaim, M. (2012). Heterogeneous information exposure and technology adoption: the case of tissue culture bananas in Kenya. *Agricultural Economics, 43*(5), 473-486. doi:10.1111/j.1574-0862.2012.00597.x

Kacharo, D. K., Mvena, Z. S. K., & Sife, A. S. (2018). Factors constraining rural households' use of mobile phones in accessing agricultural information in Southern Ethiopia. *African Journal of Science, Technology, Innovation and Development, 11*(1), 37-44. doi:10.1080/20421338.2018.1541336

Kamrath, C., Wesana, J., Broring, S., & De Steur, H. (2019). What Do We Know About Chain Actors' Evaluation of New Food Technologies? A Systematic Review of Consumer and Farmer Studies. *Comprehensive reviews in food science and food safety, 18*(3), 798-816. doi:10.1111/1541-4337.12442

Kaske, D., Mvena, Z. S. K., & Sife, A. S. (2017). Mobile Phone Usage for Accessing Agricultural Information in southern Ethiopia. *Journal of Agricultural & Food Information, 19*(3), 284-298. doi:10.1080/10496505.2017.1371023

Kassem, H. S., Alotaibi, B. A., Ghoneim, Y. A., & Diab, A. M. (2020). Mobile-based advisory services for sustainable agriculture: Assessing farmers' information behavior. *Information Development, 37*(3), 483-495. doi:Artn 0266666920967979

Keerthi, P., & Gautam, V. (2021). Factors Driving the Adoption of Mobile Phones in the Agriculture Sector: A Literature Review. *The IUP journal of Marketing management, 20*(4).

Kenny, U., & Regan, A. (2021). Co-designing a smartphone app for and with farmers: Empathising with end-users' values and needs. *Journal of Rural Studies, 82*, 148-160. doi:10.1016/j.jrurstud.2020.12.009

Khan, N. A., Gao, Q. J., Ali, S., Shahbaz, B., & Shah, A. A. (2019). Farmers' use of mobile phone for accessing agricultural information in Pakistan: a case of Punjab province. *Ciencia Rural, 49*(10). doi:ARTN e20181016

Khan, N. A., Gao, Q. J., Sertse, S. F., Nabi, M. N., & Khan, P. (2020). Farmers' use of mobile phone-based farm advisory services in Punjab, Pakistan. *Information Development, 36*(3), 390-402. doi:Artn 0266666919864126

Krell, N. T., Giroux, S. A., Guido, Z., Hannah, C., Lopus, S. E., Caylor, K. K., & Evans, T. P. (2020). Smallholder farmers' use of mobile phone services in central Kenya. *Climate and Development, 13*(3), 215-227. doi:10.1080/17565529.2020.1748847

Landmann, D., Lagerkvist, C. J., & Otter, V. (2020). Determinants of Small-Scale Farmers' Intention to Use Smartphones for Generating Agricultural Knowledge in Developing Countries: Evidence from Rural

India. *European Journal of Development Research, 33*(6), 1435-1454. doi:10.1057/s41287-020-00284-x
Leary, R. M. (2012). *Introduction to behavioral research methods* (6th ed. ed.).
Lubua, E. W., & Kyobe, M. E. (2019). The Influence of Socioeconomic Factors to the Use of Mobile Phones in the Agricultural Sector of Tanzania. *African Journal of Information Systems, 11*(4), 352-366. Retrieved from <Go to ISI>://WOS:000488624100006
Madlabana, C. Z., Mashamba-Thompson, T. P., & Petersen, I. (2020). Performance management methods and practices among nurses in primary health care settings: a systematic scoping review protocol. *Systematic reviews, 9*(1), 40. doi:10.1186/s13643-020-01294-w
Martins, C., Oliveira, T., & Popovic, A. (2014). Understanding the Internet banking adoption: A unified theory of acceptance and use of technology and perceived risk application. *International Journal of Information Management, 34*(1), 1-13. doi:10.1016/j.ijinfomgt.2013.06.002
Mendes, J., Pinho, T. M., dos Santos, F. N., Sousa, J. J., Peres, E., Boaventura-Cunha, J., Morais, R. (2020). Smartphone Applications Targeting Precision Agriculture Practices-A Systematic Review. *Agronomy-Basel, 10*(6). doi:10.3390/agronomy10060855
Mgbenka, R. N., Mbah, N., & Ezeano, C. I. (2015). A Review of Small holder Farming in Nigeria: Need for Transformation. *Agricultural Engineering Research Journal*. doi:10.5829/idosi.aerj.2015.5.2.1134
Michels, M., Bonke, V., & Musshoff, O. (2019). Understanding the adoption of smartphone apps in dairy herd management. *Journal of Dairy Science, 102*(10), 9422-9434. doi:10.3168/jds.2019-16489
Michels, M., Bonke, V., & Musshoff, O. (2020). Understanding the adoption of smartphone apps in crop protection. *Precision Agriculture, 21*(6), 1209-1226. doi:10.1007/s11119-020-09715-5
Michels, M., Fecke, W., Feil, J. H., Musshoff, O., Pigisch, J., & Krone, S. (2020). Smartphone adoption and use in agriculture: empirical evidence from Germany. *Precision Agriculture, 21*(2), 403-425. doi:10.1007/s11119-019-09675-5
Michie, S., Johnston, M., Francis, J., Hardeman, W., & Eccles, M. (2008). From theory to intervention: Mapping theoretically derived behavioural determinants to behaviour change techniques. *Applied Psychology-an International Review-Psychologie Appliquee-Revue Internationale, 57*(4), 660-680. doi:10.1111/j.1464-0597.2008.00341.x
Misaki, E., Apiola, M., Gaiani, S., & Tedre, M. (2018). Challenges facing sub-Saharan small-scale farmers in accessing farming information through mobile phones: A systematic literature review. *Electronic Journal of Information Systems in Developing Countries, 84*(4). doi:10.1002/isd2.12034
Mittal, S., & Mehar, M. (2016). Socio-economic Factors Affecting Adoption of Modern Information and Communication Technology by Farmers in India: Analysis Using Multivariate Probit Model. *Journal of Agricultural Education & Extension, 22*(2), 199-212. doi:10.1080/1389224x.2014.997255
Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRIsMa statement doi:10.1136/bmj.b2535
Molina-Maturano, J., Verhulst, N., Tur-Cardona, J., Guerena, D. T., Gardeazabal-Monsalve, A., Govaerts, B., & Speelman, S. (2021). Understanding Smallholder Farmers' Intention to Adopt Agricultural Apps: The Role of Mastery Approach and Innovation Hubs in Mexico. *Agronomy-Basel, 11*(2). doi:10.3390/agronomy11020194
Mugambiwa, S. S., & Tirivangasi, H. M. (2017). Climate change: A threat towards achieving 'Sustainable Development Goal number two' (end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. *Jamba (Potchefstroom, South Africa), 9*(1), 350. doi:10.4102/jamba.v9i1.350
Mwalukasa, N., Mlozi, M. R. S., & Sanga, C. A. (2018). Influence of socio-demographic factors on the use of mobile phones in accessing rice information on climate change adaptation in Tanzania. *Global Knowledge Memory and Communication, 67*(8-9), 566-584. doi:10.1108/Gkmc-01-2018-0006

Mwalupaso, G. E., Wang, S. G., Xu, Z. X., & Tian, X. (2019). Towards Auspicious Agricultural Informatization-Implication of Farmers' Behavioral Intention Apropos of Mobile Phone Use in Agriculture. *Sustainability, 11*(22). doi:10.3390/su11226282

Mwangi, M., & Kariuki, S. (2015). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development, 6*.

Mwantimwa, K. (2017). Use of mobile phones among agro-pastoralist communities in Tanzania. *Information Development, 35*(2), 230-244. doi:10.1177/0266666917739952

Nabhani, I., Daryanto, A., Machfud, M., & Rifin, A. (2016). Mobile Broadband for the Farmers: A Case Study of Technology Adoption by Cocoa Farmers in Southern East Java, Indonesia. *Agris on-line Papers in Economics and Informatics, 08*(02), 111-120. doi:10.7160/aol.2016.080209

Nakasone, E., Torero, M., & Minten, B. (2014). The Power of Information: The ICT Revolution in Agricultural Development. In G. C. Rausser (Ed.), *Annual Review of Resource Economics, Vol 6* (Vol. 6, pp. 533-550).

Narine, L. K., Harder, A., & Roberts, T. G. (2019). Farmers' intention to use text messaging for extension services in Trinidad. *Journal of Agricultural Education & Extension, 25*(4), 293-306. doi:10.1080/1389224x.2019.1629970

Ng, L., Pitt, V., Huckvale, K., Clavisi, O., Turner, T., Gruen, R., & Elliott, J. H. (2014). Title and Abstract Screening and Evaluation in Systematic Reviews (TASER): a pilot randomised controlled trial of title and abstract screening by medical students.

Nikam, V., Kumar, S., & Kingsly, I. M. (2021). Social network factors affecting adoption of Mobile app by farmers. *Indian Journal of Agricultural Sciences, 91*(2), 13-17. Retrieved from <Go to ISI>://WOS:000638091500002

Nyamba, Y. S., & Malongo, R. S. M. (2012). Factors Influencing the Use of Mobile Phones in Communicating Agricultural Information: A Case of Kilolo District, Iringa, Tanzania. *International Journal of Information and Communication Technology Research, 2*(7).

Obisesan, A. A. (2014). Gender Differences In Technology Adoption And Welfare Impact Among Nigerian Farming Households.

Ogunniyi, M. D., & Ojebuyi, B. R. (2016). Mobile Phone Use for Agribusiness by Farmers in Southwest Nigeria. *Journal of Agricultural Extension, 20*(2), 172-187. doi:10.4314/jae.v20i2.13

Okello, J. J., Kirui, O., Njiraini, G. W., & Gitonga, Z. (2012). Drivers of Use of Information and Communication Technologies by Farm Households: The Case of Smallholder Farmers in Kenya. *Journal of Agricultural Science, 4*(2). doi:10.5539/jas.v4n2p111

Olum, S., Gellynck, X., Juvinal, J., Ongeng, D., & De Steur, H. (2019). Farmers' adoption of agricultural innovations: A systematic review on willingness to pay studies. *Outlook on Agriculture, 49*(3), 187-203. doi:10.1177/0030727019879453

Oluwamayokun , A. F., Anoma, A., & Ammar, A. A. (2022). Factors influencing technology adoption among smallholder farmers: a systematic review in Africa. *Journal of Agriculture and Rural Development in the Tropics and Subtropics, 123*(1), 13–30. doi:10.17170/kobra-202201195569

Omar, Q., Yap, C. S., Ho, P. L., & Keling, W. (2021). Predictors of behavioral intention to adopt e-AgriFinance app among the farmers in Sarawak, Malaysia. *British Food Journal, 124*(1), 239-254. doi:10.1108/Bfj-04-2021-0449

Otene, V. A., Ezihe, J. A. C., & Torgenga, F. S. (2017). Assessment of Mobile Phone Usage Among Farmers in Keana Local Government Area of Nasarawa State, Nigeria. *Journal of Agricultural & Food Information, 19*(2), 141-148. doi:10.1080/10496505.2017.1361829

Owusu, A. B., Yankson, P. W. K., & Frimpong, S. (2017). Smallholder farmers' knowledge of mobile telephone use: Gender perspectives and implications for agricultural market development. *Progress in Development Studies, 18*(1), 36-51. doi:10.1177/1464993417735389

Pace, R., Pluye, P., Bartlett, G., Macaulay, A. C., Salsberg, J., Jagosh, J., & Seller, R. (2012). Testing the reliability and efficiency of the pilot Mixed Methods Appraisal Tool (MMAT) for systematic mixed studies review. *International journal of nursing studies, 49*(1), 47-53. doi:10.1016/j.ijnurstu.2011.07.002

Parikh, P., Aparo, N. O., Nordhagen, S., & De Steur, H. (2022). Food safety-related perspectives and practices of consumers and vendors in Ethiopia: A scoping review. *Food Research International, 157*. doi:10.1016/j.foodres.2022.111376

Parlasca, M. C. (2021). A vital technology: Review of the literature on mobile phone use among pastoralists. *Journal of International Development, 33*(4), 780-799. doi:10.1002/jid.3540

Petticrew, M., & Roberts, H. M. (2006). *Systematic Reviews in the Social Sciences.* , Hoboken, NJ.

Pongnumkul, S., Chaovalit, P., & Surasvadi, N. (2015). Applications of Smartphone-Based Sensors in Agriculture: A Systematic Review of Research. *Journal of Sensors, 2015*. doi:10.1155/2015/195308

Prestwich, A., Sniehotta, F. F., Whittington, C., Dombrowski, S. U., Rogers, L., & Michie, S. (2014). Does theory influence the effectiveness of health behavior interventions? Meta-analysis. *Health psychology : official journal of the Division of Health Psychology, American Psychological Association, 33*(5), 465-474. doi:10.1037/a0032853

Radovic-Markovic, M., Kabir, M. S., & Jovicic, E. (2020). Gender and Technology Adoption among Farmers in Banglash. *International Review*(3-4), 12-28. Retrieved from <Go to ISI>://WOS:000607634500001

Rahman, A. M. A., & Fadol, I. O. (2013). Influence of Socioeconomic Characteristics on Purposes for which Mobile Phone was used by Small Scale Farmers in the Gezira State, Sudan. *IJASRT in EESs,*.

Ronald, O., Basil, M., & David, P. P. (2018). Determinants of mobile phones usage in sweet potato vine business in Gulu district northern Uganda. *African Journal of Agricultural Research, 13*(21), 1071-1079. doi:10.5897/ajar2017.12213

Schalkwyk, F. v., Young, A., & Verhulst, S. (2017). *GHANA Esoko – Leveling the Information Playing Field for Smallholder Farmers in Ghana*. Retrieved from

Schilling, J. (2006). On the Pragmatics of Qualitative Assessment. *European Journal of Psychological Assessment, 22*(1), 28-37. doi:10.1027/1015-5759.22.1.28

Schulz, P., Prior, J., Kahn, L., & Hinch, G. (2021). Exploring the role of smartphone apps for livestock farmers: data management, extension and informed decision making. *Journal of Agricultural Education & Extension*. doi:10.1080/1389224x.2021.1910524

Shikuku, K. M., Okello, J. J., Sindi, K., Low, J. W., & McEwan, M. (2017). Effect of Farmers' Multidimensional Beliefs on Adoption of Biofortified Crops: Evidence from Sweetpotato Farmers in Tanzania. *The Journal of Development Studies, 55*(2), 227-242. doi:10.1080/00220388.2017.1414188

Sikundla, T., Mushunje, A., & Akinyemi, B. E. (2018). Socioeconomic drivers of mobile phone adoption for marketing among smallholder irrigation farmers in South Africa. *Cogent Social Sciences, 4*(1). doi: 10.1080/23311886.2018.1505415

Simera, I., Moher, D., Hoey, J., Schulz, K. F., & Altman, D. G. (2010). A catalogue of reporting guidelines for health research. *European journal of clinical investigation, 40*(1), 35-53. doi:10.1111/j.1365-2362.2009.02234.x

Stafford-Smith, M., Griggs, D., Gaffney, O., Ullah, F., Reyers, B., Kanie, N., O'Connell, D. (2017). Integration: the key to implementing the Sustainable Development Goals. *Sustainability science, 12*(6), 911-919. doi:10.1007/s11625-016-0383-3

Tanrikulu, Z., & Ozturan, M. (2012). Farmers' Beliefs about Using Mobile Devices for Livestock Management: Case of Turkey. *Journal of Animal and Veterinary Advances, 11*(10), 1546-1551. Retrieved from <Go to ISI>://WOS:000305332100006

Teo, T. (2010). Examining the influence of subjective norm and facilitating conditions on the intention to use technology among pre-service teachers: a structural equation modeling of an extended

technology acceptance model. *Asia Pacific Education Review, 11*(2), 253-262. doi:10.1007/s12564-009-9066-4

Thar, S. P., Ramilan, T., Farquharson, R. J., Pang, A., & Chen, D. (2020). An empirical analysis of the use of agricultural mobile applications among smallholder farmers in Myanmar. *The Electronic Journal of Information Systems in Developing Countries, 87*(2). doi:10.1002/isd2.12159

Theis, S., Lefore, N., Meinzen-Dick, R., & Bryan, E. (2018). What happens after technology adoption? Gendered aspects of small-scale irrigation technologies in Ethiopia, Ghana, and Tanzania. *Agriculture and Human Values, 35*(3), 671-684. doi:10.1007/s10460-018-9862-8

Venkatesh, V., & Davis, F. D. (1996). A Model of the Antecedents of Perceived Ease of Use: Development and Test. *Decision Sciences, 27*(3).

Venkatesh, V., Michael, G. M., Gordon, B. D., & Fred, D. D. (2003). User Acceptance of Information Technology: Toward a Unified View *Mis Quarterly*.

Venkatesh, V., & Morris, M. G. (2000). Why don't men ever stop to ask for directions? gender, social influence, and their role in technology acceptance and usage behavior. *Gender in Technology Acceptance and Usage, 24*.

Verma, P., & Sinha, N. (2018). Integrating perceived economic wellbeing to technology acceptance model: The case of mobile based agricultural extension service. *Technological Forecasting and Social Change, 126*, 207-216. doi:10.1016/j.techfore.2017.08.013

Victor, O., Nic, J. L., & Xiaomeng, L. (2021). Factors affecting the adoption of mobile applications by farmers: An empirical investigation. *African Journal of Agricultural Research, 17*(1), 19-29. doi:10.5897/ajar2020.14909

Wely, v. M. (2014). The good, the bad and the ugly: meta-analyses. *Human reproduction (Oxford, England), 29*(8), 1622-1626. doi:10.1093/humrep/deu127

Wyche, S., & Steinfield, C. (2015). Why Don't Farmers Use Cell Phones to Access Market Prices? Technology Affordances and Barriers to Market Information Services Adoption in Rural Kenya. *Information Technology for Development, 22*(2), 320-333. doi:10.1080/02681102.2015.1048184

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Table 1: The PCC Framework

	Definition
Population The target population is **farmers.**	For this review, a "farmer" refers to anyone engaged in agriculture, raising livestock, fish, or growing crops for food, raw materials, or other commercial reasons and owns or hires the production land.
Concept The fundamental concept of this review **is the adoption of mobile phone technology.**	To serve the aim of this review, "adoption" was taken to mean the acceptance, integration, and use of an innovation/ technology (MPT for our case), Mobile phone technology encompasses all mobile phones, smartphones, and applications
Context Global	This review targets studies in both developed and developing countries.

PCC= *Population, Concept and Context framework (Hannes & Macaitis, 2012; Ng et al., 2014) was utilized to define the key components of this review.

Table 2: Types of MPTs and behavioral theories reported in the included studies

	n	References
Theories/models		
TAM	10	(Kabbiri et al., 2018; Kacharo, Mvena, & Sife, 2018; Landmann, Lagerkvist and Otter, 2020 ; Nabhani et al., 2016; Sikundla, Mushunje, & Akinyemi, 2018; Verma & Sinha, 2018; Okoroji, Lees & Lucock 2021)
UTAUT	7	(Beza et al., 2018; Michels, Bonke, and Musshoff, 2020; Molina-Maturano et al., 2021; Mwalukasa et al., 2018; Narine, Harder, & Roberts, 2019; Omar et al., 2021)
Other theories	11	(Abdullahi, Oladele, & Yusuf, 2019; Bonke et al., 2018; Folitse et al., 2018; Kabirigi et al., 2022; Krell et al., 2020)
Type of MPT		
Mobile (smart) phone	19	(Abdullahi, Oladele & Akinyemi, 2021; Folitse et al., 2018; Hoang & Drysdale, 2021; Kabirigi et al., 2022; Kenny & Regan, 2021; Lubua & Kyobe, 2019; Otene, Ezihe, & Torgenga, 2017)
Decisions Support Applications (DSA)	14	(Bonke et al., 2018; Krell et al., 2020; Michels, Bonke, & Musshoff, 2019; Michels, Bonke, & Musshoff, 2020; Molina-Maturano et al., 2021; Nikam, Kumar, & Kingsly, 2021; Owusu, Yankson, & Frimpong, 2017; Thar et al., 2021)
Text messaging applications (SMS)	13	(Abdullahi, Oladele, & Yusuf, 2019; Aricat & Ling, 2017; Islam & Gronlund, 2011; Kaske et al., 2017; Khan et al., 2019; Narine, Harder, & Roberts, 2019)
Social media applications	7	(Abdullahi, Oladele, & Yusuf, 2019; Aricat & Ling, 2017; Khan et al., 2019; Krell et al., 2020) (Aricat & Ling, 2017; Kaske et al., 2017; Khan et al., 2019)
News/information applications	7	(Abdullahi, Oladele, & Yusuf, 2019; Asravor, Boakye, & Essuman, 2021 ; Khan et al., 2020)
Others	8	

Comments: *Other theories refer to theories that were mentioned by at most two studies, and they include affordance theory, graph theory, goal-orientation theory, Goal-based behavioral model (MGB); Theory of reasoned action (TRA), Integrative Approach to Models of Technology Adoption (IAMTA); household behavior theory, theory of information and communication technology for development, social cognitive theory, Actor-Network theory, and model of personal computer use. TAM = Technology acceptance model; UTAUT = Unified Theory of acceptance and use of technology. DSA identified through this review include crop protection apps, Agri-info, and advisory apps; market information systems, livestock management apps; camera function apps; and disease and weather forecast apps.*
n is the number of studies in each category in the table

Table 3: A table of reported indicators of MPT adoption and their measurement

	Adoption indicator	Measurement	Reference
1	Mobile phone ownership	• Dummy variable requiring Yes/No responses (Y=1 for households that own and use the mobile phones and Y=0 otherwise); • Discrete choice responses: owns a phone, has access, no access	(Abdullahi, Oladele, & Yusuf, 2019; Aricat & Ling, 2017; Asravor, Boakye, & Essuman, 2021; Folitse et al., 2018; Islam & Gronlund, 2011; Animashaun et al., 2014; Krell et al., 2020; Michels, Bonke, & Musshoff, 2020)
2	Behavioral intention	• Likert scales (5-point, 7-point) • Dummy variable ((1 = 'I intend to MPT to communicate with extension officers,' and 0 = 'I do not intend to MPT to communicate with extension officers.'))	(Aldosari et al., 2017; Beza et al., 2018; Landmann, Lagerkvist and Otter, 2020; Molina-Maturano et al., 2021; Mwalupaso et al., 2019; Nabhani et al., 2016; Narine, Harder, & Roberts, 2019 ; Omar et al., 2021; Otene, Ezihe, & Torgenga, 2017; Verma & Sinha, 2018; Okoroji, Lees & Lucock 2021)
3	Generic MPT use	• Likert scales (5-point • Number of mobile phone activities, e.g., dialed call, received call, sent short message service (SMS), received SMS, listening to the radio); • number of mobile phones and sim cards • Dummy variable (1: user; 2: non-user; 1 = farmer used mobile phone, 2 = otherwise, 1= adopted, 0 if otherwise)	(Abdullahi, Oladele, & Akinyemi, 2021; Aldosari et al., 2017; Folitse et al., 2018; Girma & Kelil, 2021; Kabirigi et al., 2022; Kacharo, Mvena, & Sife, 2019; Kaske et al., 2017; Kassem et al., 2020; Mwalukasa et al., 2018; Mwalupaso et al., 2019; Mwantimwa, 2017; Nyamba & Mlozi, 2012)
4	Use intensity	• Likert Scales (3-point, 4-point, 5-point, 6-point • Number of transactions (sending/receiving money, saving, paying bills, calls, SMS I a day, week, or month, (daily, weekly, and monthly)	(Abdullahi, Oladele, & Yusuf, 2019; Asravor, Boakye, & Essuman, 2021; Filippini et al., 2020; Hoang & Drysdale, 2021; Islam & Gronlund, 2011; AL; Lubua & Kyobe, 2019; Michels et al., 2020; Ogunniyi & Ojebuyi, 2016; Otene, Ezihe, & Torgenga, 2017)
5	Use frequency	• Likert scale (5-point, 6-point) • Discrete choices: daily, weekly, monthly	(Filippini et al., 2020; Islam & Gronlund, 2011; Lubua & Kyobe, 2019; Michels et al., 2020; Mwantimwa, 2017)
6	Adoption	• Dummy variable (adoption= 1, 0 otherwise; 1 = adoption of crop protection smartphone app; 0 = non-adoption; 1=adopter, 0= non-adopter); Yes/No responses • Likert Scale (5-point)	(Alam et al., 2018; Kabbiri et al., 2018; Michels, Bonke, & Musshoff, 2020; Nikam, Kumar, & Kingsly, 2021 ; Owusu, Yankson, & Frimpong, 2017; Sikundla, Mushunje, & Akinyemi, 2018)
7	Attitude	• Likert scale (4-point, 5-point)	(Abdullahi, Oladele, & Akinyemi, 2021; Kassem et al., 2020; Schulz et al., 2021; Tanrikulu & Ozturan, 2012; Thar et al., 2020)
8	Perception	• Likert Scale (5-point)	(Bonke et al., 2018; Kabirigi et al., 2022; Kenny & Regan, 2021; Lubua & Kyobe, 2019)

9	Knowledge	• Discrete choice (True or False)	(Abdullahi, Oladele, & Akinyemi, 2021)
10	Willingness to Adopt	• Likert scale (5-point)	(Diaz et al., 2021)
11	Constraints	• Likert scale (4-point) • Yes/No responses	(Abdullahi, Oladele, & Akinyemi, 2021; Kabirigi et al., 2022; Kenny & Regan, 2021; Mwantimwa, 2019)
12	Willingness to pay	• Likert Scale (5-point); • Yes/No responses	(Bonke et al., 2018)

Note; the references above are only for studies that indicated how the indicators were measured. It does not reflect the total number of studies that measured these indicators, and caution is advised when interpreting these.

Remarks: **Sample statement to measure behavioral intention** "I am planning to use a smartphone to generate agricultural knowledge" (scale 1 = strongly disagree to 5 = strongly agree) by Landmann, Lagerkvist, and Otter (2020) and "I plan to use or continue using mobile phone apps frequently that provide agronomic information" (scale 1= totally disagree to 7= totally agree) by Molina-Maturano et al. (2021). Note: the construct behavioral intention was measured using different number of items. For example, 3 items (Beza et al., 2018; Molina-Maturano et al., 2021); 2 items Landmann, Lagerkvist and Otter (2020), and 5 items (Omar et al., 2021; Okoroji, Lees & Lucock 2021). **Measurement of behavioral intention** as a binary variable where 1 = 'I intend to use text messaging to communicate with extension officers,' and 0 = 'I do not intend to use text messaging to communicate with extension officers.' Taken from Narine, Harder, & Roberts (2019). Measurement of willingness-to-pay: "Farmers were asked if they were willing to pay a yearly fee for a crop protection app which included all of the functions they perceive as useful (responses: Yes/No)" (Bonke et al., 2018); Measurement of mobile phone adoption: (MPA = 1, 0 otherwise) where farmers that use mobile phone for calls, SMS or both in agricultural marketing are considered adopter, whereas those that have never used mobile phone services (i.e. calls and SMS or both) for agricultural marketing are considered as non-adopters" taken from Sikundla, Mushunje, & Akinyemi (2018) .Measurement of Mobile phone ownership: "1, if the farmer has a smartphone; 0 otherwise 1, if the farmer has a mobile phone; 0 otherwise" (Michels, Bonke, & Musshoff, 2020). The majority of studies did not provide the measurement items that were used to measure various constructs and indicators.

Table 4: A table of determinants of farmers' MPT adoption

Category of determinants	Significant variables	Effects	References
Socio-demographic variables	Age	Inconclusive (+/-)	(Animashaun et al., 2014; Filippini et al., 2020; Folitse et al., 2018; Hoang, 2020; Hoang & Drysdale, 2021; Islam & Gronlund, 2011; Kabirigi et al., 2022; Kacharo, Mvena, & Sife, 2018; Khan et al., 2020; Krell et al., 2020; Mwalukasa et al., 2018; Mwantimwa, 2019; Thar et al., 2020)
	Farming experience	Inconclusive (+/-)	(Folitse et al., 2018; Kaske et al., 2017; Mwalupaso et al., 2019)
	Gender	Inconclusive (+/-)	(Filippini et al., 2020; Folitse et al., 2018; Hoang, 2020; Animashaun et al., 2014; Mwalukasa et al., 2018; Mwantimwa, 2017; Otene, Ezihe, & Torgenga, 2017; Sikundla, Mushunje, & Akinyemi, 2018; Thar et al., 2020)
	Marital status	Inconclusive (+/-)	(Animashaun et al., 2014; Mwalukasa et al., 2018; Mwalupaso et al., 2019; Mwantimwa, 2017; Otene, Ezihe, & Torgenga, 2017)
	Farm size	Inconclusive (+/-)	(Folitse et al., 2018; Girma & Kelil, 2021; Hoang & Drysdale, 2021; Kacharo, Mvena, & Sife, 2018; Michels et al., 2020; Mwalukasa et al., 2018; Narine, Harder, & Roberts, 2019; Otene, Ezihe, & Torgenga, 2017; Tanrikulu & Ozturan, 2012)
	Income	Inconclusive (+/-)	(Girma & Kelil, 2021; Hoang, 2020; Hoang & Drysdale, 2021; Kacharo, Mvena, & Sife, 2018; Kaske et al., 2017; Mwantimwa, 2017; Otene, Ezihe, & Torgenga, 2017; Sikundla, Mushunje, & Akinyemi, 2018; Tanrikulu & Ozturan, 2012)
	Education	Inconclusive (+/I)	(Girma & Kelil, 2021; Hoang, 2020; Hoang & Drysdale, 2021; Animashaun et al., 2014; Khan et al., 2020; Krell et al., 2020; Michels, Bonke, & Musshoff, 2020; Michels et al., 2020; Mwalukasa et al., 2018; Nikam, Kumar, & Kingsly, 2021; Otene, Ezihe, & Torgenga, 2017; S. P. Thar et al., 2020)
	Number of dependents	Positive (+)	(Islam & Gronlund, 2011)
	Household size	Inconclusive (+/-)	(Animashaun et al., 2014)
Technological factors and Mobile use related attributes	Duration of (MP ownership)	Positive	(Kacharo, Mvena, & Sife, 2018; Kaske et al., 2017; Khan et al., 2020)
	Farmers' skill and aptitude	Positive (+)	(Khan et al., 2020)

	Number of MP	Positive (+)	(Diaz et al., 2021; Kaske et al., 2017; Khan et al., 2020; Mwalukasa et al., 2018)
	Experience	Positive (+)	(Beza et al., 2018; Folitse et al., 2018; Kacharo, Mvena, & Sife, 2018; Kaske et al., 2017; Mwalukasa et al., 2018; Narine, Harder, & Roberts, 2019; Owusu, Yankson, & Frimpong, 2017; Tanrikulu & Ozturan, 2012)
	Mobile phone ownership	Positive (+)	(Aldosari et al., 2017; Aricat & Ling, 2017; Asravor, Boakye, & Essuman, 2021; Folitse et al., 2018; Islam & Gronlund, 2011; Khan et al., 2019; Krell et al., 2020; Nyamba & Mlozi, 2012)
	Perceived ease of use	Inconclusive (+/-)	(Kabbiri et al., 2018; Landmann, Lagerkvist and Otter, 2020 ; Michels, Bonke, & Musshoff, 2019; Nabhani et al., 2016)
	Perceived usefulness	Inconclusive (+/-)	(Diaz et al., 2021; Kabbiri et al., 2018; Kaske et al., 2017; Verma & Sinha, 2018; Okoroji, Lees & Lucock 2021)
	Performance expectancy	Positive (+)	(Michels, Bonke, & Musshoff, 2020; Narine, Harder, & Roberts, 2019; Omar et al., 2021)
	Effort expectancy	Positive (+)	(Michels, Bonke, & Musshoff, 2020; Narine, Harder, & Roberts, 2019; Omar et al., 2021)
	Perceived cost	Inconclusive (+/-)	(Diaz et al., 2021; Mwalukasa et al., 2018; Omar et al., 2021)
	Perceived advantage	Positive (+)	(Kabbiri et al., 2018; Kaske et al., 2017)
Psychological/behavioral factors	Attitude/	Positive (+)	(Abdullahi, Oladele, & Akinyemi, 2021; Kaske et al., 2017; Landmann, Lagerkvist and Otter, 2020; Mwalupaso et al., 2019; Tanrikulu & Ozturan, 2012; Thar et al., 2020; Verma & Sinha, 2018)
	Self-efficacy	Positive (+)	(Landmann, Lagerkvist and Otter, 2020)
	Social influence	Positive (+)	(Beza et al., 2018; Diaz et al., 2021; Michels, Bonke, & Musshoff, 2020; Molina-Maturano et al., 2021; Nabhani et al., 2016; Narine, Harder, & Roberts, 2019 ; Omar et al., 2021; Otene, Ezihe, & Torgenga, 2017; Verma & Sinha, 2018; Okoroji, Lees & Lucock , 2021)
	Intention to use	Positive (+)	(Diaz et al., 2021; Michels, Bonke, & Musshoff, 2020; Michels et al., 2020; Omar et al., 2021; Okoroji, Lees & Lucock 2021)
	Information need and seeking behavior	Positive (+)	(Kacharo, Mvena, & Sife, 2018)
	Perceived innovativeness	Negative (-)	(Beza et al., 2018; Bonke et al., 2018; Diaz et al., 2021; Michels, Bonke, & Musshoff, 2019; Molina-Maturano et al., 2021)
	Emotion	Positive (+)	(Landmann, Lagerkvist and Otter, 2020)
	Perception	Positive (+)	(Abdullahi, Oladele, & Akinyemi, 2021; Bonke et al., 2018; Kaske et al., 2017; Khan et al., 2019; Owusu, Yankson, & Frimpong, 2017; Thar et al., 2020)
	Habit	Positive (+)	(Beza et al., 2018; Landmann, Lagerkvist and Otter, 2020)
	Perceived reliability of mobile phone services	Positive (+)	(Kacharo, Mvena, & Sife, 2018; Kaske et al., 2017)
	Trust	Positive (+)	(Beza et al., 2018; Kassem et al., 2020; Molina-Maturano et al., 2021; Okoroji, Lees & Lucock ,2021)

Constraints and Institutional factors	Information awareness	Positive (+)	(Diaz et al., 2021; Folitse et al., 2018; Kassem et al., 2020; Otene, Ezihe, & Torgenga, 2017; Okoroji, Lees & Lucock, 2021)
	Knowledge of Apps	Positive (+)	(Abdullahi, Oladele, & Akinyemi, 2021; Michels, Bonke, & Musshoff, 2019)
	Type and quality of agricultural information	Positive (+)	(Nyamba & Mlozi, 2012)
	Access to electricity	Inconclusive (+/-)	Hoang, 2020; Hoang & Drysdale, 2021)
	Distance from market center	Negative (-)	(Filippini et al., 2020; Folitse et al., 2018; Hoang, 2020; Animashaun et al., 2014; Kacharo, Mvena, & Sife, 2018; Mwalupaso et al., 2019; Thar et al., 2020)
	Distance from the nearest town	Negative (-)	(Mwalupaso et al., 2019; Thar et al., 2020)
	Assets	Positive (+)	(Krell et al., 2020)
	Group membership	Inconclusive (+/-)	(Hoang, 2020; Krell et al., 2020; Mwalupaso et al., 2019)
	Network capacity of the farmer	Positive (+)	(Filippini et al., 2020)
	Credit access/credit program participation	Positive (+)	(Girma & Kelil, 2021; Hoang, 2020)
	Facilitating conditions	Positive (+)	(Beza et al., 2018; Michels, Bonke, & Musshoff, 2020; Molina-Maturano et al., 2021; Ogunniyi & Ojebuyi, 2016; Omar et al., 2021)
	Constraints	Negative	(Falola & Adewumi, 2012; Kacharo, Mvena, & Sife, 2018; Kaske et al., 2017; Kenny & Regan, 2021; Krell et al., 2020; Mwantimwa, 2019; Nyamba & Mlozi, 2012; Ogunniyi & Ojebuyi, 2016; Otene, Ezihe, & Torgenga, 2017; Obong, Mugonola & Paul Phillips, 2018; Thar et al., 2020; Wyche & Steinfield, 2015)
Biophysical factors	Landholding	Negative	(Nikam, Kumar, & Kingsly, 2021)
	Area under cultivation	Inconclusive (+/-)	(Mwalukasa et al., 2018; Nikam, Kumar, & Kingsly, 2021)
	Diversification	Inconclusive	(Animashaun et al., 2014; Bonke et al., 2018; Kabirigi et al., 2022; Kassem et al., 2020; Thar et al., 2020)
	Farm type	Positive	(Kabirigi et al., 2022)

Table 5: A table of characteristics and quality of the included studies

	Categories reported	Percentage of studies in each category
Publication year	2011	1.8%
	2012	7.5%
	2013	1.8%
	2014	1.8%
	2015	1.8%
	2016	3.7%
	2017	11.3%
	2018	16.9%
	2019	15.0%
	2020	15.0%
	2021	22.6%
	2022	1.8%
Geographic distribution of studies	Africa	53%
	Asia	28%
	Europe	13%
	America	4%
	Australia	1.8%
Setting	Rural	47.0%
	Urban	6.0%
	Peri-urban/Rural	4.0%
	Not specified	43.0%
Type of farming activity	Crop production	21.0%
	Livestock production	17.0%
	Mixed farming	11.0%
	Not specified	51.0%
Scale of production	Small scale farmer	30.0%
	Medium Scale farmer	2.0%
	Large scale farmer	4.0%
	Not specified	64.0%
Research method and design	Quantitative descriptive	75.4%
	Qualitative	5.6%
	Mixed methods	19.0%
	Cross-sectional design	100%
MMAT Criteria met	0% (-)	11.3%
	40% (**)	13.2%
	60% (***)	41.5%
	80% (****)	26.5%
	100% (*****)	7.5%

Note: Africa includes South Africa, Nigeria, Kenya, Uganda, Ghana, Ethiopia, Tanzania, Zambia; Asia includes India, Myanmar, Kingdom of Saudi Arabia, Vietnam, Bangladesh, Pakistan, and Malaysia; Europe has Germany, Turkey, Italy; North America includes Mexico; Oceania includes Australia; South America includes Trinidad.

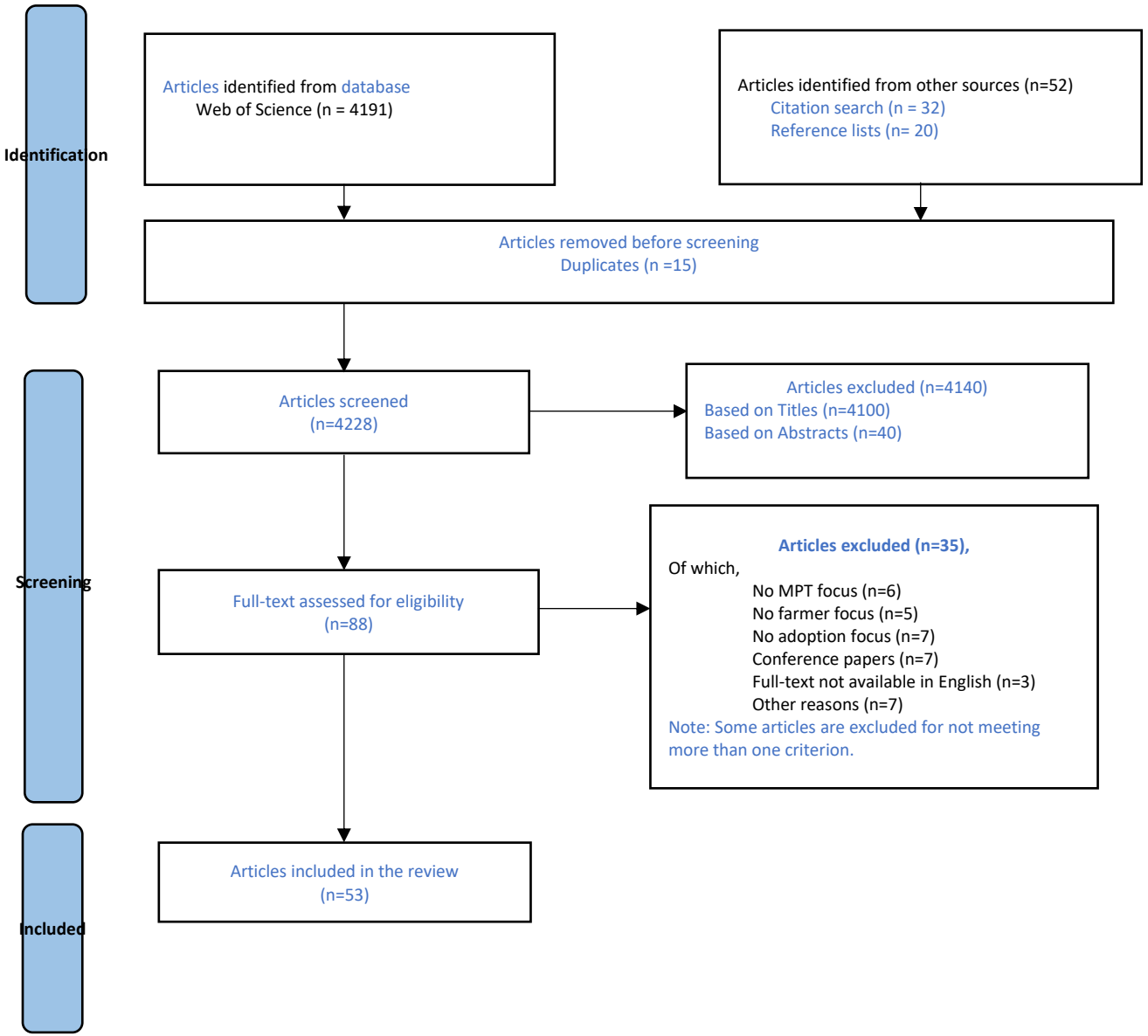

Figure 1: A PRISMA flow chart of the detailed screening strategy for identified studies

Remark: Studies were only included in the systematic review if they met all inclusion criteria. In total, 53 articles met the eligibility criteria.

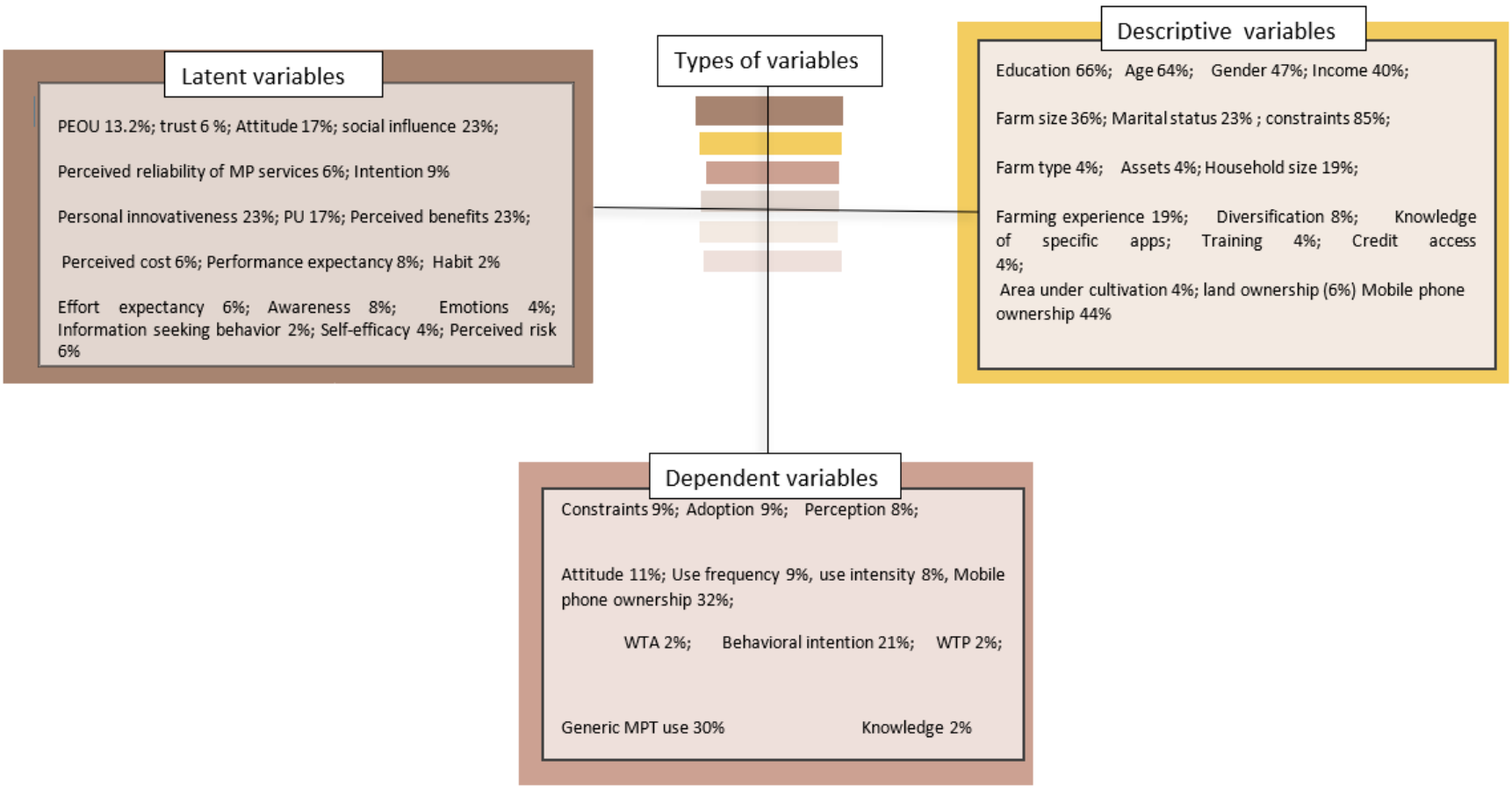

Figure 2: Type of variables

Note: Intention and attitude were reported as latent variables predicting MPT adoption and an outcome measure (dependent variable). Likewise, mobile phone ownership and constraints were both descriptive and dependent variables. Percentages for the variables in Figure 2 were calculated as a percentage of the number of included studies that measured them divided by the total number of articles included.