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Factors influencing technology adoption among smallholder farmers: a systematic review in Africa

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Abstract

Smallholder agriculture has been identified to be critical in the creation of employment, improving food security and improving the economy. However, smallholder agriculture in Africa is characterised by a low production level which has been linked to the limited use of technologies. Several factors influence the adoption of technologies among smallholder farmers in Africa. This systematic literature review focuses on the factors influencing technology adoption among smallholder farmers in Africa and identified 128 peer-reviewed papers in English between January 2000 to December 2019. The majority were carried out in Kenya, Uganda, and Malawi, with the major crops being maize, legumes and rice. This review identified 29 factors that were broadly classified into five main categories: (i) farmers' characteristics; (ii) farm characteristics; (iii) technology characteristics; (iv) institutional factors; and (v) finance. Of these, finance (81 articles), gender of household head (71 articles), age (68 articles), education (64 articles), farm size (62 articles) and extension access (59 articles) are the most prominent factors mentioned. The factors identified in this review were then related to existing technology adoption theories, and it was concluded that finance does not adequately feature in any of these extant theories. As illustrated by the relatively high occurrence of finance, this review puts forward a comprehensive framework for technology adoption and also provides critical recommendations to improve technology adoption among smallholder farmers in Africa.

Keywords: adoption, agriculture, finance, smallholder farmers, technology adoption

1 Introduction

Agriculture plays a significant role in the economic growth of developing countries (Islam, 2016; Diallo *et al*., 2020). This is reflected in the United Nations Sustainable Development Goal second goal – to end hunger, achieve food security, improve nutrition and promote sustainable agriculture (United Nations, 2015). In most developing countries, agriculture is primarily practised by smallholder farmers, and it has been identified as a crucial link in achieving the aim of the second Sustainable Development Goal (Rapsomanikis, 2015). For this reason, greater focus has been placed on the development of smallholder agriculture in developing countries (Röttger, 2015).

In Africa, 73 % of the rural population consists of smallholder farmers, and they make up about 80 % of total farmers (Arias *et al*., 2013; Rapsomanikis, 2015). Smallholder farmers produce up to 70 % of the total food consumed in the continent, account for 15-21 % of Gross Domestic Product (GDP) and employ around 60-80 % of women in Africa (Food and Agricultural Organisation, 1995; Marris, 2018; United Nations, 2015; World Bank, 2018). The development and expansion of smallholder agriculture in Africa can increase agricultural production, reduce food expenditure and raise the income level of smallholder farmers, all of which could lead to poverty reduction (Salami *et al*., 2017). This is evidenced in the 2008 report of the World Development Bank, where it was observed that in Africa, the growth in GDP attributed to agriculture was about four times more effective in reducing poverty than the GDP of other sectors (World Bank, 2008).

To increase agricultural production, the OECD-FAO (2016) noted that there must be either a significant increase in farm input resources or changes in current farming processes. Significant increments in farm inputs involve increased usage of seeds, fertilisers, herbicides and the expansion of farmland size. Evidence has shown that African

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countries have achieved agricultural growth through the expansion of cultivated land rather than through yield increase per hectare (Pretty *et al*., 2011). While increasing farm inputs might increase yield, it only provides short-term increments, which are not sustainable (Zeng *et al*., 2018). On the other hand, by implementing changes to farming processes through the use of improved or new technologies, farm yield and production per hectare can be sustainably increased (Kuhlmann & Brodersen, 2001; Wambugu *et al*., 2018). However, smallholder farming in Africa is characterised by low production volumes, reflecting the limited uptake of improved or new technologies (Poole, 2017; Salami *et al*., 2017).

Given that the population of Africa is projected to be about 2.4 billion in 2050, which is double the current population, Africa's ability to support this number without a significant change in the agricultural system is unsustainable (Adenle *et al*., 2017; United Nations, 2019). It has been argued that to develop smallholder agriculture in Africa, there is an urgent need for new and significant investments in the development of agricultural research and technology directed towards improving production (Jones & Ejeta, 2016). Hounkonnou *et al*. (2012) noted that the overall and sustainable intensification of smallholder farming through adopting improved and new technologies was crucial to food security and the reduction of poverty in Africa. Technology adoption in smallholder farming in Africa is also essential as it enhances operational efficiency (Mudege *et al*., 2018), increases farm production (Yigezu *et al*., 2018), creates farm employment (Mabuza *et al*., 2016), improves nutrition (Quisumbing *et al*., 2004), and enhances food security (Hendriks, 2014). Additionally, the use of technology in agriculture has been instrumental in assisting smallholder farmers in adapting to changing climatic conditions (Tambo & Abdoulaye, 2012), monitoring crop development and disease incidences (Van den Berg & Jiggins, 2007). Without purposeful attention paid to the adoption of technology by smallholder farmers in Africa, smallholder farming may not be able to effectively contribute to improving food security, creating employment and combatting poverty.

In recent years, the attention of African governments and agriculture stakeholders has shifted towards the improvement and provision of technology to smallholder farmers (Senbet & Simbanegavi, 2017; MacCarthy *et al*., 2018). While several benefits have been ascribed to the adoption of new technologies in smallholder farming in Africa, a large number of smallholder farmers are still unable to adopt these technologies due to a range of factors (Moser & Barrett, 2003; Yila & Thapa, 2008; Mwangi & Kariuki, 2015; Glover *et al*., 2019; Jha *et al*., 2019). In a developed country such as the United States of America, factors such as weather, flood, frost, price volatility, pest infestation, and seasonal availability of labour were identified as factors that influence technology adoption among smallholder farmers (Chavas & Kim, 2010; Chavas *et al*., 2010; Schimmelpfennig, 2016). On the other hand, in China, factors such as education, age, and family size were identified as some of the major factors that influence smallholders' technology adoption (Li *et al*., 2020; Si *et al*., 2021). This indicates that the factors that influence technology adoption among smallholder farmers can differ between regions and countries. Therefore, there is a need to build an understanding around the underlying factors behind the adoption of technology in smallholder farming in Africa'.

This systematic literature review focuses on the adoption of technology by smallholder farmers in Africa and aims to answer the following questions: (i) what are the factors that influence the adoption of technology by smallholder farmers in Africa? (ii) have the factors identified in this systematic literature review been integrated into existing theories on technology adoption? and (iii) what are some possible solutions for improving technology among smallholder farmers in Africa? This review will provide new perspectives that can inform governments, smallholder farmers, other stakeholders, and policymakers on ways to improve technology adoption by smallholder farmers in Africa.

1.1 Technology, technology adoption in smallholder agriculture in Africa

Technology in agriculture is vital in improving farm efficiency and production (Mwangi & Kariuki, 2015). The definition varies depending on the context of the research and the view of the researcher (Ainissyifa *et al*., 2018). Technology in agriculture can be broadly divided into two categories. The first category refers to the hardware aspect or technology-as-object category, also regarded as machinery (Choi, 2009, p. 50). They are technical assemblies in the form of a device or gadget used to increase agricultural performance. It includes tractors, ploughs, harrows, planters, and sprayers (Ito, 2010). The second category is technology-as-process which includes scientific processes, ideas and improvements over previous methods (Choi, 2009, p. 50). This includes herbicides, pesticides, fertilisers, hybrid seeds, plant spacing, and irrigation methods considered useful in agriculture.

The type of technology and its availability differ from one country to another. For instance, in the United States, technologies in agriculture can include the use of sophisticated techniques such as robots, temperature and moisture sensors, aerial images and global positioning system tech-

nologies that allow farms to be more efficient and profitable (USDA, 2018). On the other hand, in Africa, particularly in smallholder farming, agricultural technologies typically include hybrid seeds and improved farm inputs (Araya & Mohammed, 2014), machinery (Jain *et al*., 2009), conservation agriculture (Baudron *et al*., 2009), irrigation (Mutekwa & Kusangaya, 2006), improved agronomic practices (Witt *et al*., 2006) and other processes that contribute to the growth of agricultural production (Jain *et al*., 2009). While these technologies are not as complex as those available in developed countries, they are improvements over the traditional farming methods and are the most feasible options to improve the level of smallholder farm production in Africa (Mwangi & Kariuki, 2015).

According to Mwangi & Kariuki (2015), technology adoption in agriculture is the mental process the smallholder farmer goes through from hearing about a technology to the point of actual utilisation. Loevinsohn *et al*. (2012) define technology adoption as the integration of new technologies into existing farming systems through a period of trying and some degree of adaptation. Technology adoption can be measured by (i) the rate of adoption - the relative speed at which farmers adopt new technology, which is dependent on the extent to which a technology has been tried or tested (Pannell *et al*., 2011); and (ii) the intensity of adoption - the level of use of a given technology for a specified period (Yigezu *et al*., 2018).

The adoption of technology in smallholder agriculture underpins the increase in farm production level, and it is expected to lead to the much-needed transformation of the agricultural sector (Adesugba & Mavrotas, 2016; Bachewe *et al*., 2018). Additionally, Kaine (2008) suggests that adopting agricultural technology creates multiple direct and indirect benefits for smallholder farmers. It improves farm efficiency and increases farm yield, which leads to an increase in food supply and household food intake, creates employment, reduces poverty, increases GDP and makes a significant contribution to the economic development of Africa (World Bank, 2008).

2 Materials and methods

This study follows a systematic literature review method and uses the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram (Tricco *et al*., 2018). It is a dynamic review of the current literature, allowing the identification of recent knowledge in the current field of study (Colicchia & Strozzi, 2012). This review method further provides an overview and critical assessment of previous research or existing knowledge and identifies novel opportunities for future research (Alvesson & Sandberg, 2018).

Additionally, a systematic literature review is a rigorous, protocol-driven, transparent and unbiased form of literature review (Mallett *et al*., 2012). It is described as a reliable and comprehensive method of review involving identifying, synthesising and assessing all available evidence, quantitative and/or qualitative, to generate a robust, empirically derived answer to a focused research question (Mallett *et al*., 2012; Van der Knaap *et al*., 2008).

2.1 Scope

For any study to be considered for inclusion in this review, discussions within the study had to primarily revolve around the adoption of technology among smallholder farmers in Africa. To maintain consistency and keep to a targeted area of research, this review considered studies carried out on crops. Articles discussing livestock were excluded.

The databases used for this review include Scopus, Web of Science and JSTOR. These databases were selected because they have a large collection of abstracts and peer-reviewed studies from international publishers in diverse science areas (Baier-Fuentes *et al*., 2019; Dias *et al*., 2019). Additionally, articles from databases were used because they offer precise citations, quality-controlled indexed journals and are grouped according to subjects (Aguillo, 2012). The articles included in this review are peer-reviewed articles published from January 2000 to December 2019. The year 2000 was chosen as the starting year because it marks the commencement of sustainable agricultural development goals in Africa.

2.2 Search

In this phase, the keywords *agric** or *farm** and *technology** and *adoption** were used in the title. Additional search terms of *smallholder** and *Africa** were introduced. The search was carried out using specific search strings highlighted in Supplementary material A. The review was limited to peer-reviewed articles published in English because the dissemination of scientific knowledge is fundamentally done in this language and is a criterion in many reviews (López-Fernández *et al*., 2016). The search resulted in 426 articles.

2.3 Screening

The title and abstracts of the studies identified were read, and those that did not mention technology adoption, smallholder farmer, smallholder farming and Africa were excluded. A multi-stage screening involving reading the title and abstract, and in some instances, a partial or full-text

review process was then carried out. A total of 73 duplicate articles were identified and eliminated, while 43 articles were eliminated based on geographical location. Only studies carried out in Africa were considered for this review. Based on the subject of study, 182 articles were eliminated as they did not relate to the adoption of agricultural technology among smallholder farmers in Africa, neither was there a mention of any crop in the articles. The final number of selected articles was 128 (Fig. 1). A summary of

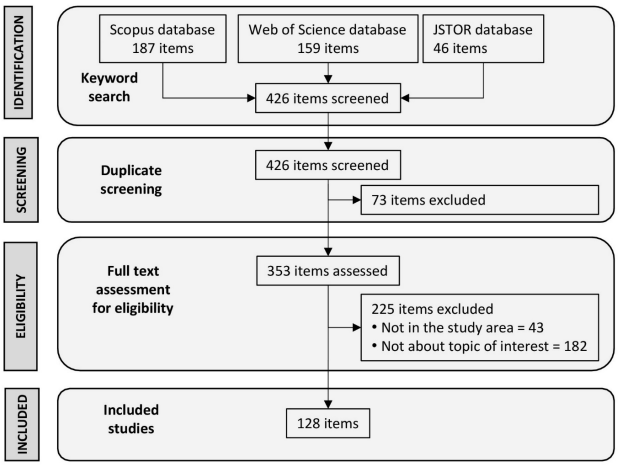

Fig. 1: *Article selection process.*
Derived from using the PRISMA flow diagram.

the authors, publication year, major findings, study location and factors identified in the reviewed articles were recorded (Supplementary material B).

2.4 Data extraction

At the full-text stage, the studies were read, and relevant data extracted (Supplementary material A). This included bibliographic information, crops studied, technology observed, methodological information and significant constraints.

2.5 Data synthesis

The studies were described based on their year of publication. The articles were then grouped according to the crops studied and the location of the study. The factors influencing the adoption of technology identified in the reviewed articles were highlighted. The factors were classified based on the similarities of their attributes, and they were further distributed according to the location of the study. Each of the factors identified in this review was discussed with regards to its influence on the adoption of technology by smallholder farmers in Africa. The data synthesis is presented in the result and discussion section.

3 Results

3.1 Descriptive analysis

The factors that influence technology adoption among smallholder farmers in Africa are significant, and several studies have been carried out in this regard (Ncube, 2018; Krah *et al*., 2019). The number of articles published per year from 2014 is higher than those published from 2000 to 2013 (Fig. 2). The highest number of articles (16) was published in 2018. The increase in the frequency of publications since 2014 can be attributed to the fact that the African Union marked 2014 as the "Year of Agriculture and Food Security" (Food and Agricultural Organisation, 2017). This spurred increased attention in developing smallholder agriculture in Africa in terms of technological development (Senbet & Simbanegavi, 2017). The articles were further

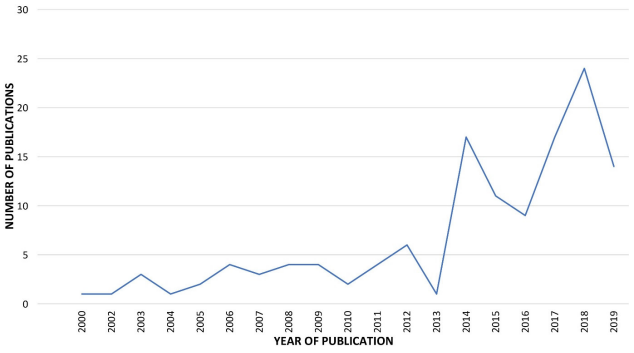

Fig. 2: *Publications per year.*
Data were derived from the 128 articles selected for this literature review.

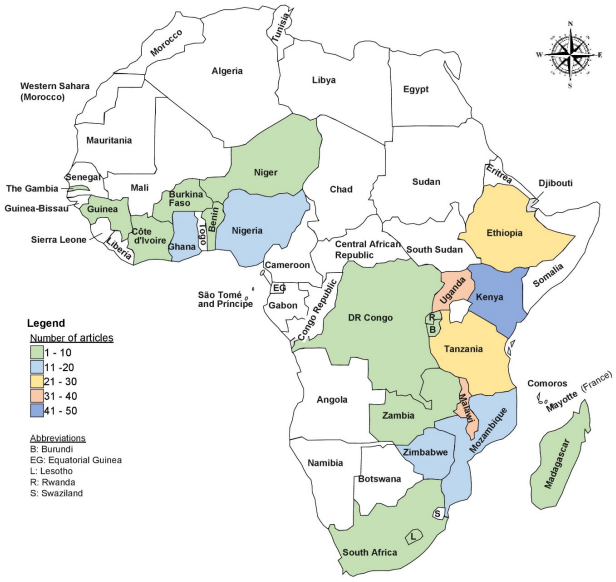

Fig. 3: *Distribution of the articles by country.*
Map was derived from the 128 articles selected for this literature review.

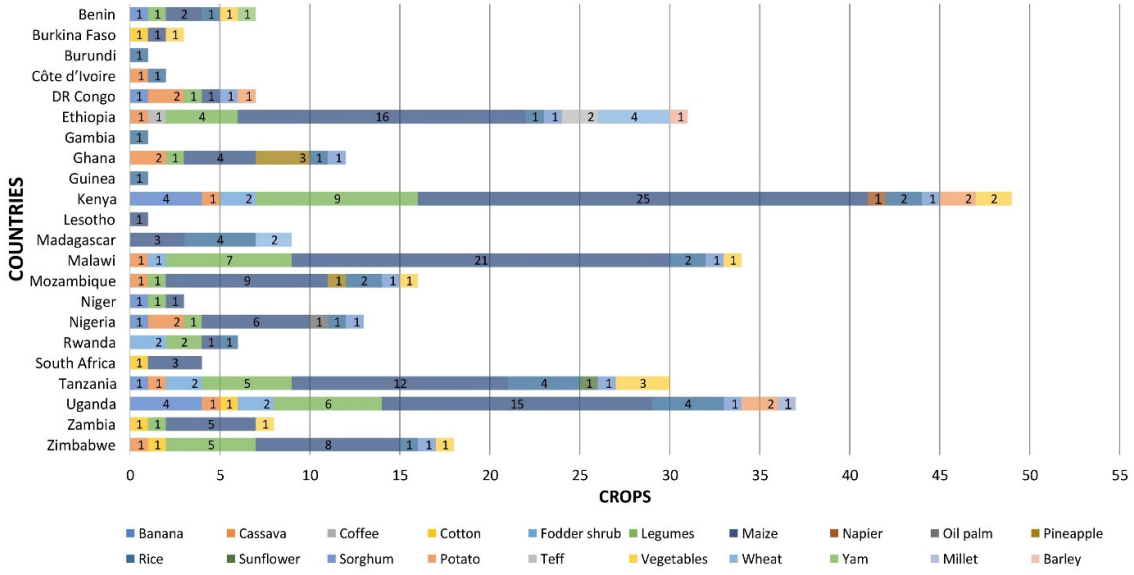

Fig. 4: *Distribution of articles by crops.*
Data were derived from the 128 articles selected for this literature review.

grouped based on the crops studied and the location in which they were studied. Crops such as cowpeas, soybeans and pigeon peas were classified as legumes, while amaranth was classified as a vegetable. In total, 18 crops were identified. Secondly, the articles were grouped based on the frequency of their study in each location (Supplementary material C). The majority of studies (40) were carried out in Kenya (Fig. 3).

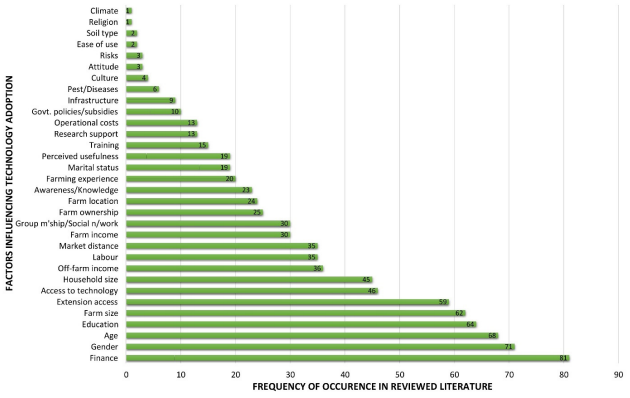

Fig. 5: *Factors influencing technology adoption among smallholder farmers in Africa.*
Data were derived from the 128 articles selected for this literature review.

A quick review of the articles grouped by location indicated that the majority of the studies were carried out in Kenya, Uganda and Malawi, with the three prominent crops being maize, rice and legumes (Fig. 4). Maize was identified as occupying approximately 34.69 % of the farmland in Africa, providing a nutrient source for human consumption as well as inputs for other industries. Rice and legumes occupy approximately 11 % and 10 % (Food and Agricultural Organisation, 2018; Macauley & Ramadjita, 2015). The importance of maize in Africa has prompted the drive to improve its production. Hence, several studies have focused on maize cultivation and its related activities (Ministry of Agriculture Development, 2016; Tanumihardjo *et al*., 2019).

The systematic literature review revealed 29 factors that influence technology adoption, of which finance, age, gender, extension access, technology access and education were prominent (Fig. 5).

Given that the household income of the smallholder farmer is a sum of the off-farm and farm income (Baiyegunhi *et al*., 2019), studies that mentioned household income were counted as both off-farm and farm income.

4 Discussion

4.1 Factors that influence technology adoption among smallholder farmers in Africa

The adoption of new technology by smallholder farmers in Africa is influenced by a variety of factors (Tey *et al*., 2017; Jha *et al*., 2019). This is because smallholder farmers need to learn the application of new technologies and processes, as well as how to integrate these new technologies and processes into existing systems (Salami *et al*., 2017). We identified 29 factors in this literature review, which were broadly classified into five categories: (i) farmers' characteristics; (ii) farm characteristics; (iii) technology characteristics; (iv) institutional factors; and (v) finance (Table 1).

Table 1: *Factors influencing technology adoption and their frequency in reviewed articles.*

Category (i) *Farmer's characteristics*	*Category (ii)* *Farm characteristics*	*Category (ii)* *Technology characteristics*	*Category (iv)* *Institutional factors*	*Category (v)* *Finance*
Age (51)	Extension access (43)	Access to technology (39)	Research support (12)	Finance (81)
Gender (49)	Farm size (38)	Awareness & knowledge (15)	Infrastructure (6)	Accessibility (65)
Education (41)	Farm income (29)	Perceived usefulness (16)	Government policies (6)	Availability (27)
Household size (33)	Labour (25)	Training (11)		Affordability (10)
Off-farm income (27)	Farm ownership (22)	Operating cost (7)		
Group membership (19)	Market distance (22)	Ease of use (2)		
Marital status (18)	Farm location (12)			
Farming experience (18)	Pest & disease incidence (5)			
Attitude (3)				
Culture (3)				
Religion (1)				

Note: Data were derived from the 128 articles selected for this literature review.
Figures in brackets represent the number frequency of occurrence of the factor in the articles reviewed.

4.1.1 Farmers' characteristics

This review indicated that several studies on technology adoption in Africa have attempted to explain the characteristics of individual smallholder farmer's that affects technology adoption. These include the farmer's age, gender, education, marital status, household size, off-farm income, farming experience, group membership, attitude, culture and religion (Makate *et al*., 2018; Mutenje *et al*., 2019; Okello *et al*., 2019; Oyinbo *et al*., 2019; Vidogbéna *et al*., 2016).

The age of the individual smallholder farmer was associated with declining interest in new and developing technologies (Okello *et al*., 2019). It was identified that when older smallholder farmers adopt new technologies, they do so under the influence of other factors such as the relative cost of the technology, perceived ease of use, and perceived advantage of the use of the new technology (Wesseler *et al*., 2017). Additionally, in the study of technology adoption among smallholder farmers in Kenya, Kinyangi (2014) observed that aside from being slow to embrace new technology, older smallholder farmers, in some cases, avoided new technology. In the study by Michalscheck *et al*. (2018), gender was also found to significantly affect the adoption of new agricultural technologies by smallholder farmers in Africa. It was noted that men and women have different preferences when choosing which technology to adopt, with male smallholder farmers observed to adopt new technology faster than female smallholder farmers (Mudhara *et al*., 2003; Murage *et al*., 2015). However, in situations where the household is headed by a female, their decision to adopt new agricultural technologies is sometimes affected by their farm size (Fisher & Carr, 2015).

Similarly, from the reviewed articles, it was identified that the education level of smallholder farmers in Africa had a positive influence on their rate of technology adoption (Oyinbo *et al*., 2019). Smallholder farmers who were considered educated - with some form of formal or informal education - adopt new technologies faster than uneducated smallholder farmers (Chirwa, 2005; Kassie *et al*., 2015). Likewise, the marital status of the smallholder farmer was noted to influence their technology adoption decisions (Omotilewa *et al*., 2019). When compared with single smallholder farmers, married smallholder farmers were noted to adopt new technologies late because having family commitments constrains their limited available financial resources which they need to adopt new technologies (Matata *et al*., 2010). Additionally, in the study by Claessens *et al*. (2012), the household size of the smallholder farmer was identified as a measure of labour availability and financial commitment. The larger the smallholder farmer's family, the higher the smallholder farmer's financial commitment, and the lower the likelihood of adopting new technologies due to financial (Orr, 2000).

Off-farm income was another factor noted in the reviewed articles to have a positive impact on smallholder farmer' technology adoption in Africa (Mudhara *et al*., 2003; Ojiem *et al*., 2006). This is because off-farm income often serves as an alternative for the smallholder farmers to overcome financial constraints, which can be used to adopt new technologies. For instance, in the study by Diiro (2013) in Uganda on the impact of off-farm income on the intensity of technology adoption of improved maize varieties, it was noted that there was a significantly higher adoption intensity among households with off-farm income compared with their counterparts without off-farm income.

The number of years of farming experience of the smallholder farmer was another crucial factor of technology adoption identified in the reviewed articles. The more the experience of the smallholder farmer is in farming or cultivating specific crops, the more they are aware of what technology is needed and to what extent the technology is to be used (Matata *et al*., 2010). Where there is limited farming experience coupled with a vacuum of information about the technology to be adopted, the rate of adoption of new technology was noted to be low (Araya & Mohammed, 2014). Orr (2000) and Mutekwa and Kusangaya (2006) in their studies noted that belonging to a social group enhanced smallholder farmers' peer learning and encouraged the sharing of knowledge on the benefits of new technologies, which positively influenced the adoption rate of new technologies (Muriithi *et al*., 2018). Also, the attitude of individual smallholder farmers in the reviewed articles influenced their adoption of new agricultural technology (Senyolo *et al*., 2018). Relatedly, Wale and Yalew (2007), in their study on farmers' variety preference in Ethiopia, found that attitude was influenced by the level of education. The more educated the smallholder farmers are, the more they are aware of the benefits of using new technologies, thus increasing their rate of technology adoption (Murage *et al*., 2015; Mushunje *et al*., 2011).

Interestingly, culture and religion were observed to influence technology adoption either by network formation through group membership or local norms (Dawson *et al*., 2016). However, Altieri (2018) observed that culture and religion had neither a negative nor positive influence on the rate of adoption of agricultural technology in Africa. While several characteristics of the smallholder farmers were identified as factors that influence technology adoption, it was noted that they do not act in isolation. Rather, they interacted collectively to define the outcome of the smallholder farmer's decision to adopt new technologies.

4.1.2 Farm characteristics

Access to extension services was identified as one of the farm characteristics that influence technology adoption among smallholder farmers in Africa. Adejuwon (2018) and Oyinbo *et al*. (2019) reported that the availability of extension services had a positive effect on the adoption of new technologies by smallholder farmers. Extension agents helped to inform smallholder farmers about new technologies and their benefits. This enhanced the smallholder farmers' rate of technology adoption. Another important characteristic of the farm that was identified to influence technology adoption is the size of the farm (Makate *et al*., 2019). Smallholder farmers in some parts of Africa are characterised by farm size of ≤ 2 ha, but ≤ 5 ha in Nigeria (Rapsomanikis, 2015). Smallholder farmers with large farm sizes were noted to adopt new technologies faster than smallholder farmers with smaller farm sizes. For example, a smallholder farmer with a farm size of about 4 ha tended to adopt technology faster than another smallholder farmer who cultivated only 1 ha.

Among the articles reviewed, Mudhara *et al*. (2003) identified farm income as a factor that influences technology adoption. Marenya & Barrett (2007) and Walker *et al*. (2012) noted further that smallholder farmers who generated higher farm income had better financial capability to adopt newer technologies. The availability of labour was also regarded as an important factor that influenced technology adoption among smallholder farmers in Africa (Dadi *et al*., 2004). Michalscheck *et al*. (2018), in their study on model results versus farmers' realities, noted that smallholder farmers in regions with limited labourers tended to adopt technology faster. Also, land ownership structure affected the decision to adopt new agricultural technology (Makate *et al*., 2019; Nhamo *et al*., 2014). A proper land ownership structure was found to encourage smallholder farmers' adoption of new technologies (Ojiem *et al*., 2006). On the other hand, lack of a proper land ownership structure was found to discourage the adoption of large scale agricultural technology (Djurfeldt *et al*., 2014).

Additionally, Fischer & Qaim (2012) identified that the smallholder farmers' distance from the market where they sell their produce and the market where they get their technology influenced the adoption of technology. Similarly, Mwololo *et al*. (2019), in their study on the determinant of extension service on farm diversity in Kenya, found that the location of the farm relative to the location of the source of technology was an important factor that determined the rate of technology adoption. Many agricultural research institutes, where new technologies emanate, are located in the city centre; hence, farms located in or near the city centre receive technology earlier and tend to adopt technology at a faster rate (Barbier *et al*., 2009; Nkonya *et al*., 2005). Kassie *et al*. (2015) reemphasised that the main goal of every smallholder farmer is to improve their farm production. However, disease and pest infestation can cause farm produce to be reduced or lost entirely, whether at pre-harvest or post-harvest. It was further noted that the incidence of some pests and diseases is relative to a specific location; as such, it can influence the type of pesticide and herbicide to be adopted by the smallholder farmer (Kurgat *et al*., 2018).

4.1.3 Technology characteristics

For technology to be adopted, the technology needs to be accessible to smallholder farmers (Andrade *et al*., 2019).

Brown *et al*. (2019), in their study on the progression of adoption of technology in Eastern and Southern Africa, noted that smallholder farmers are more likely to adopt technologies that are accessible. Also, Ochieng *et al*. (2019) observed that smallholder farmers adopted technology that they were aware of or knowledgeable about its uses. However, Abdul-Hanan (2017) concluded that being aware of a technology alone might not lead to its adoption. Therefore, It is important for smallholder farmers to know about the technology, its application, and its benefits in order to enhance adoption. Consequently, for long-term adoption, smallholder farmers need to be trained in how to use and, in some instances, how to maintain these new technologies (Krah *et al*., 2019).

Following the awareness of a technology, smallholder farmers were also found to adopt technologies that they perceive as useful, consistent with their needs, and easily adaptable to their farm (Okello *et al*., 2019). Another key determinant of technology adoption identified in the reviewed articles was the net cost of the technology, which includes the acquisition and operating costs (Foster & Rosenzweig, 2010). Also, Michalscheck *et al*. (2018) and Akrofi *et al*. (2019) reported that high costs associated with agricultural technologies often hindered the adoption of such technologies. Consequently, Senyolo *et al*. (2018) noted that smallholder farmers in Africa tended to avoid technologies that were costly to acquire and operate. Consequent to the characteristics of technology that were identified to influence adoption, smallholder farmers were observed to adopt new technologies based on how easy they are to use in terms of physical and mental requirements (Smale & Mason, 2014).

4.1.4 Institutional factors

The provision and access of smallholder farmers to infrastructure was noted to influence and encourage technology adoption (Kassie *et al*., 2015). Wambugu *et al*. (2011) noted that the adoption of new technology by smallholder farmers was also influenced by government policies. The study highlighted that governments often put policies in place to promote or discontinue specific technologies, depending on the outcome to be achieved. In such instances, the promoted technologies are adopted faster by smallholder farmers as the government will provide the required training and research support. Additionally, Smale & De Groote (2003) and Senthilkumar *et al*. (2018) noted that the availability of basic infrastructures such as roads and water influenced smallholder farmers' decision to adopt new technology.

4.1.5 Finance

Finance was identified as a factor that influenced technology adoption by 81 out of the 128 articles reviewed in this study. Studies have reported a high correlation between finance and technology adoption among smallholder farmers in Africa because most of these technologies are costly to acquire and maintain (Diagne, 2009; Habtemariam *et al*., 2019; Makate *et al*., 2019; Mudhara *et al*., 2003). Finance was noted to empower smallholder farmers to purchase, operate and maintain new technologies (Fisher & Carr, 2015). Additionally, smallholder farmers are able to use finance to hire labour, acquire farmland, and get the required education and training. This will further facilitate the adoption of new technologies by smallholder farmers.

The farmers' farm income, also known as economic farm surplus or operating profit, include the sale of farm-related products and services, while off-farm income is generated from non-farm related activities and services (Moran, 2009; Holmes Sackett, 2020). In the context of this study, we describe finance to be financial intervention from finance providers such as Banks, government agencies, or any other financial oriented institution. The availability, accessibility and affordability of finance were found to influence technology adoption by the studies of International Finance Corporation (2011), Awotide *et al*. (2015) and Akrofi *et al*. (2019), respectively. Apart from using finance for adopting technology, it was found that smallholder farmers also depend on finance to explore fallback options should the newly adopted technology fail (Oyinbo *et al*., 2019).

4.2 Relating the identified factors with existing technology adoption theories

Technology adoption is a complex nonlinear process influenced by multiple factors (Meijer *et al*., 2015). While it is beyond the scope of this study to provide an in-depth discussion on the theories on technology adoption, it is critical to understand the dynamic relationship between existing adoption theories and the influencing factors identified in this literature review.

In this section, we examined a range of technology adoption theories and classified them based on their focus. The factors identified in this literature review were then matched against the classified group of theories (Table 2). This enables the development of a comprehensive framework of factors that influence technology adoption in the context of smallholder farming in Africa to identify key areas of potential improvements.

Theories in group (i), diffusion theories, are focused on the process by which innovations are communicated through

Table 2: *Categorisation of various theories of adoption based on their focus.*

Group	*(i) Diffusion theories*	*(ii) User acceptance theories*	*(iii) Decision-making theories*	*(iv) Personality theories*	*(v) Organisational structure theories*
Focus	*Technology Environment*	*Employee (farmer) interest*	*Management interest*	*Individual cognitive interest*	*Organisational interest*
Theories	• Diffusion of Innovation Theory • Technology Lifecycle Theory • Technology Implementation Process Theory	• Theory of Reasoned Action • Theory of Planned Behaviour • Technology Acceptance Model (TAM1, TAM2) • Uses and Gratification Theory • Motivational Model • User Acceptance of Information Technology	• Rational Choice Theory/ Game Theory • Decision Making under Uncertainty • Risk Management • Change Management	• Technology Lifecycle Theory • Social Cognitive Theory	• Disruptive Technology Theory • Creative Destruction Theory
Categories of factors of technology adoption identified in this review	• Farmers' characteristics • Farm characteristics • Technology characteristics • Policies and infrastructure	• Farmers' characteristics • Technology characteristic	• Farm characteristics	• Farmers' characteristics	• Farm characteristics

Adapted from Hillmer (2009).

various channels over time among members of a social system. This set of theories are concerned with the type of new technologies or ideas, why these technologies are needed, and how these technologies have spread over time (Rogers, 2010). Relative to the factors identified in this literature review, we found that factors in the farmer, farm and technology characteristics are included in the diffusion theories.

Furthermore, theories in group (ii), user acceptance theories, explain users' intention to adopt new technologies. Theories in this group were developed in the field of social psychology, and they describe adoption as a function of behavioural intentions (Lai, 2017). This behaviour is dependent on the adopter's attitude, which includes behavioural beliefs, normative beliefs and the motivation to adopt (Kaine, 2008). If a farmer perceives that adopting technology will add value to their farm, the technology is adopted. By relating this group of theories with the factors identified in this literature review, the individual (farmer's) characteristics was identified as the only set of factors considered by this set of theories. The set of theories in group (iii), decision-making theories, are concerned with the technology adoption decision making processes. The process of identifying the technology to adopt involves understanding the problem to be solved, evaluating available solutions and courses of action, collecting data and assessing probable future outcomes before selecting the best-fit technology (Okello *et al*., 2019). These theories often revolve around the organisation, and factors categorised as farm characteristics in this literature review were found to be relevant to this group of theories.

The set of theories under the personality theories group (group iv) considers the different personality attributes of the adopter that influences the adopter's reaction towards adopting new technologies. Relative to the factors identified in this literature review, the factors related to the farmers' characteristics were found to be relevant to this group of theories. Lastly, the organisational structure theories (group v), which to the best of our knowledge, has not been applied to understanding technology adoption among smallholder farmers, includes theories that relate technology adoption to the structure and values of the organisation. In this case, the attributes of the farms can be associated with the factors identified under this group of theories.

By relating the identified factors in this review to the various groups of technology adoption theories, we developed a comprehensive framework of factors that influence technology adoption among smallholder farmers in Africa (Fig. 6). Findings from the reviewed articles indicated that finance played a critical role in the adoption of technology among smallholder farmers in Africa. It involves the availability of sources of finance for smallholder farmers, the accessibility of such finance, and the affordability or cost associated with the finance. Despite its importance, finance was not uniquely identified in each group of the adoption theories. Finance might not have been considered uniquely as a factor because of the context of the studies, the view of the researchers, or perhaps because it was indirectly included in other factors. A comprehensive framework that considers finance is required so as to provide insights into the way various aspects of finance influence technology adoption by smallholder farmers in Africa. Hence, it was proposed that finance should be considered as a unique factor in technology adoption by smallholder farmers in Africa (Figure 6). The proposed comprehensive framework expands the influencing factors under consideration and brings forth the importance of finance in the adoption of technology, the development, and the sustainability of smallholder farming in Africa. Based on this framework, key areas of improvement were suggested.

5 Suggestions for improving technology adoption among smallholder African farmers

A large number of developing countries are characterised by agricultural systems that are highly improved by implementing basic changes that would provide support for the incorporation of new technologies (Wanyama *et al*., 2016). However, the adoption of technology by smallholder farmers in developing countries, such as Africa, is costly and conditional on the factors that support the adoption process (Harvey *et al*., 2014; Okalebo *et al*., 2007). Additionally, strong local capabilities are required to identify the right technologies, appropriate transfer mechanisms, and adaptations required according to local economic, social, technical and environmental conditions (Harvey *et al*., 2014). Therefore, based on the results of this systematic literature review, several preliminary recommendations are proposed to improve the adoption of technology by smallholder farmers in Africa.

Firstly, new technology that is being introduced to smallholder farmers in Africa needs to be easily adaptable to the local agricultural farming systems. If a technology does not fit into the local context of the smallholder farmer or if the smallholder farmer does not perceive the advantages of using such technology, the technology might not be adopted or have a low adoption rate (Nhamo *et al*., 2014). For example, while many international stakeholders in smallholder agriculture are actively promoting conservation agriculture to improve agricultural productivity, Chinseu *et al*. (2018) observed that smallholder farmers in Malawi continued to abandon conservation agriculture as it did not easily fit into the local farming system. This issue was also highlighted in 16 other studies identified in this literature review. Therefore, to encourage adoption, technologies need to be designed to meet the needs of the local smallholder farmers, or the technology should be adaptable to meet the local needs.

Secondly, providing training for the smallholder farmers on how to use new technology can positively contribute to technology adoption. Wanyama *et al*. (2016) in their study on the adoption of agricultural engineering technology in Uganda, observed that the slow rate of adoption was attributed to the lack of information available to the end-user smallholder farmers. This problem was highlighted by 11 of the studies identified in this review. However, programs such as field schools and Training and Visit extension systems can be used to train the smallholder farmers and facilitate the transfer of knowledge on the use and benefits of new technologies.

Thirdly, there is the need for a significant improvement in government support for the smallholder farmers in Africa to encourage the adoption of new technologies. For example, Kassie *et al*. (2015) noted that in Ethiopia, Kenya, Malawi and Tanzania, the adoption of sustainable intensification practices were influenced by the reliance on government support such as provision of inputs, advisory and technical services. The effect of government policies was reported in 18 studies considered in this review. Platforms such as the Comprehensive Africa Agriculture Development Program can be used to focus on the increased uptake of new technology by smallholder farmers in Africa. Stakeholders in agriculture, especially the government, will also be required to implement policies that encourage smallholders to adopt new technologies.

Finally, improving the availability, accessibility and affordability of finance can accelerate the adoption of new technology by smallholder farmers in Africa. Finance was highlighted as a crucial factor in the adoption of technology in Africa by 81 out of the 128 articles in this review. Due to the poor availability and accessibility of affordable finance, smallholder farmers in Africa are unable to effectively adopt new technologies (Fisher & Carr, 2015; Maliki *et al*., 2017; Oyinbo *et al*., 2019). Finance is a major limiting factor that will need to be resolved in order to improve technology adoption among smallholder farmers in Africa. More importantly, finance has been identified as the basic foundation

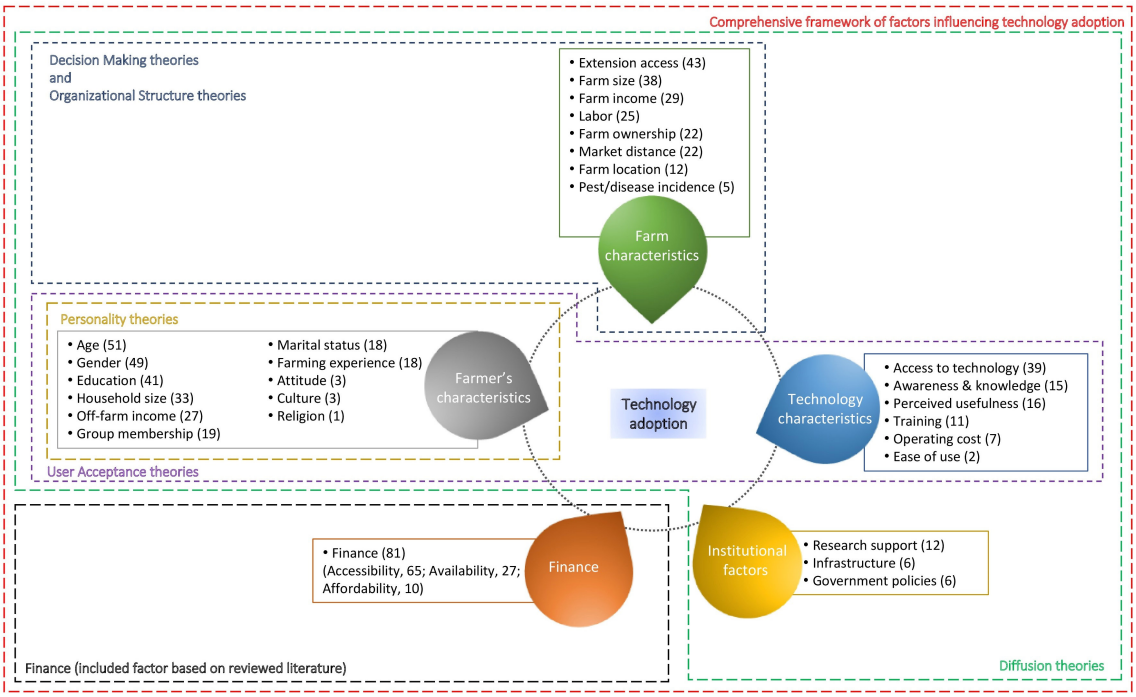

Fig. 6: *Comprehensive framework of factors that influence technology adoption.*
Data were derived from the 128 articles selected for this literature review.

for successful technology adoption in Africa. Any future recommendations put forward to improve technology adoption should be underpinned by finance.

6 Conclusion

This study systematically reviewed the literature on the adoption of technology by smallholder farmers in Africa to gather current evidence and identify gaps for future research. The review coincides with the African Union's recent focus on improving food security and the development of smallholder agriculture. If this is to be successful and sustainable, it will rely heavily on the adoption of new technologies. Evidence has shown that the adoption of technologies by smallholder farmers in Africa has been linked to higher farm production, increased earnings, reduced poverty levels, improved nutritional status, and increased employment rate. This is particularly important in Africa because 80 % of Africans rely on smallholder farming for their livelihood.

The rate of technology adoption is influenced by a complex and dynamic interaction between the different factors identified in this review. Some of the more predominant factors highlighted included finance, age, gender, access to extension, education, access to technology, and farm size. The drive towards improving technology adoption among smallholder farmers in Africa can be achieved by formulating and implementing comprehensive policies that consider these dynamic relationships. Strategically, improving financial interventions will also be crucial to enhancing technology adoption.

Finally, it is interesting to note that despite the importance of technology in advancing smallholder agriculture, the number of African countries covered in the selected articles was relatively small. Also, the articles reviewed seem to be biased geographically towards East and West Africa that were formerly colonised by the British. This could have been a result of a tactical institutional arrangement between the British and previously colonised territories. Hence, future studies should be broadened to accommodate other geographical locations.

Supplement

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