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Understanding innovation process within an interactive social network: Empirical insights from maize innovations in southern Ghana

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Abstract: Agricultural innovations propel improvement in agricultural productivity. Even though, the related literature largely reports low adoption of innovations, the literature deficiently accounts for the complexities and the interactive social contexts that embed innovation processes. In addressing the lacuna, it remains imperative to understand the complexities of the innovation process. This study assesses the factors influencing the intricate innovation processes toward the uptake of maize innovations among smallholder farmers in Ghana. The study relied on focus group discussions, observations, and individual in-depth interviews with thirty maize farmers in Kintampo District and Wenchi Municipal Assembly in Ghana. Content analysis was used to analyze the qualitative information. The findings show many instances of learning, knowledge transfer, and uptake of practices among farmers during innovation processes. We find adaptations to existing farm practices, and local contexts. With unintended outcomes which appear useful for learning and co-learning in the innovation ecosystem. The innovation processes are shaped by farmers characteristics and personal goals, trialability of technology, social network, relative advantage of the technology, access to information and extension services, and sociocultural conditions in the external environment. The farmer field schools, and field days constitute important conduits in promoting increased maize innovations uptake among farmers. We suggest that, in understanding adoption, focus should be paid to the complexities in the innovation processes reckoning that it is embedded in an interactive social network, with many instances of learning, co-learning, knowledge transfer, contestations, and negotiations. This should guide policy decisions to better inform the design of programme interventions.

Subjects: Psychological Science; Social Psychology; Human Geography

Keywords: Innovation adaptation; smallholder farmers; technology; global south

1. Introduction

Globally, the promotion of agricultural innovations continue to engage the attention of world leaders, development organizations, governments, and donors, given the apparent benefits offered in increasing smallholder farmers agricultural productivity and the promotion of specific targets set under the sustainable development goals (SDGs) including zero hunger (SDG-2), and climate action (SDG-13; Ogundari & Bolarinwa, 2018). Agricultural innovations are promoted as packages of technologies that are introduced to farmers with the expectation that farmers will adopt and utilize to derive intended economic and social benefits. The adoption of agricultural innovations has often been perceived as readymade technological packages capable of being transferred smoothly from one setting to be adopted and implemented by the end user, mostly farmers (Glover et al., 2016). This is based on the diffusion of innovation theory (Rogers, 2003), or the linear thinking (Ankrah & Freeman, 2022). Rogers (2003) defined adoption as a decision to use or reject an innovation as the best course of action available to an individual. Information on the innovation is communicated through specific channels over time among members of a social system (Rogers, 2003). The innovation process in relation to the agricultural innovation pertains more to the stages of knowledge acquisition on the new idea or practice, followed by an evaluation of the innovation leading to the formation of favorable or unfavorable attitudes toward the innovation. The innovation process starts with the knowledge stage where the individual learns about the existence of an innovation and seeks information about the innovation (Rogers, 2003). The information the individual receives about the innovation shapes the attitude(s) towards the innovation. Since the individual is embedded within a social system, social reinforcement by other friends, or peers based on their subjective evaluation of the innovation affects the individuals' opinion and beliefs about the innovation (Leeuwis & Aarts, 2021; Sahin, 2006). The adoption process moves beyond the decision to adopt or reject an innovation. It involves continued, a discontinued use, modifications, and adaptation to suit the individual's local context.

Adoption of innovations is often assessed as part of efforts to determine the success or failure of agricultural interventions. This remains central in evaluating the impact of agricultural interventions and resulting technological change in Africa's agriculture (Glover et al., 2016, 2019). Adoption rates of new agricultural innovations are often measured in evaluating farmers utilizations of the introduced innovations and for making decisions about new investments to upscale (Hermans et al., 2021; Schut et al., 2020). However, various authors have flawed the concept of adoption, criticizing the metrics of measurement as leading to inaccurate and misleading conclusions (Glover et al., 2016; Loevinsohn et al., 2012, p. 2013; Leeuwis, 2004). The challenge with understanding adoption originates from defining adoption as a binary choice option with adopters and non-adopters without providing clarity on what constitute adoption, the intensity of adoption, or recognizing the dynamic process of learning and experimentation during the technology change and transfer process (Andersson & D'Souza, 2014; Brown et al., 2017; Glover et al., 2019; Whitfield et al., 2015). A focus on binary metrics of adoption is embedded in the idea that individuals make a yes or no decision to replace old methods with new innovations (Glover et al., 2016). Such studies (examples Feleke & Zegeye, 2006; Nigatu et al., 2018; Teferi et al., 2015; Tesfaye et al., 2016; Wongnaa et al., 2018) have been criticized as overlooking the innovation process and not recognizing the multiple often complex pathways in which farmers adapt innovations to their local context (Sumberg, 2005; Whitfield et al., 2015). A strand of literature (Andersson & D'Souza, 2014) critiques the binary assessment of adoption as limiting the understanding of realizing what would be considered as full or partial adoption. The binary lens limits an understanding of farmers modification and adaptations to suit their local contexts. Studies on adoption have argued the need to rethink and move beyond the simple linear model of adopters and non-adopters to further understand the complex dynamic process that shapes the innovation process(es; Glover et al., 2019; Andersson & D'Souza, 2014; De Oca Munguia & Llewellyn, 2020; Hermans et al., 2021). Adoption is a gradual process, and often aspects or components of the innovation are adopted in different ways across a population of adopters (De Oca Munguia & Llewellyn, 2020). Leeuwis and Aarts (2021) argued that the concept of adoption is often regarded as individual decision-making process, even though individuals are part of a broader social system. Where the individual influences the social system, or also get influenced by the social system. A narrow binary perspective of the innovation process tends to overlook critical interdependencies and nuances in the innovation process(es). Leeuwis and Aarts (2021) further compliment the simple linear individualist model for explaining adoption, proposing that adoption should be assessed as a collective interactional process explained with sociological and institutional dimensions of innovation. Weersink and Fulton (2020), emphasized that, the notion of adoption should be understood as a process with multiple stages which need to be considered in sequence, influenced by economic and noneconomic factors. De Oca Munguia and Llewellyn (2020) highlighted high discrepancies in the consistency of variables used in explaining adoption with neglect of the performance of the innovations or practice and its interaction with farmers attitude and preferences. Hermans et al., (2021) proposed four lenses for understanding the complex innovation adoption dynamics, thus by understanding the social dynamics and information transfer, contextual costs and benefits, experiences and risk aversion, and practice adaptation of farmers. Uptake of innovation is not immediate, as there are many factors influencing the innovation process. Farmers demographic characteristics and personal goals, trialability and observability of the innovation, farmers social network and interaction, farmers access to information and extension services, relative advantage of the technology, sociocultural and political conditions in the external environment are crucial in shaping the innovation process.

In this article, we assess the factors influencing the innovation processes toward the uptake of innovations among smallholder maize farmers in Ghana. Maize is an important staple in Ghana with direct use in food, feed for livestock sector and industry. All social stratification (rich and poor) consumes maize products, giving striking importance to maize among Ghanaian households. Maize production in Ghana accounts for about fifty percent of the total area of local cereal crop production. National output increased from 1.47 to 3.00 million tons between 2008 and 2020 (MoFA and IFPRI, 2020). Government's interventions such as the Planting for Food and Jobs (PFJ) and Fertilizer Subsidy Programme (FSP) prioritization of maize dramatically contributed to the increases in maize output.

Although maize production is gradually increasing, average maize yield of 2.25 Mt per hectare is below the estimated achievable 6 Mt per hectare. The maize crop is, however plagued with several production challenges that drastically affect yield, thereby negatively affecting other actors along the maize value chain. The low yield of maize is due to several factors, including pest and disease infestation, drought, low soil fertility, poor agronomic practices, limited use of improved seeds, and fertilizers. Many new maize innovations have been introduced to maize farmers, which have included improved varieties, agronomic practices such as planting in rows with recommended spacing, and phytosanitary practices such as control of Fall Armyworm in order to increase farmer's productivity. These maize innovations are practices, technologies that are perceived as new by the farmers. An innovation may have been invented long ago, but if individuals perceive it as new, then it may still be an innovation for them (Rogers, 2003).

The National Agricultural Research Institutions developed and released 55 improved varieties of maize including 29 hybrid maize varieties (CSIR, 2019), however the adoption rate of these improved varieties remains very low among Ghanaian farmers (Ifie et al., 2022). A substantial number of maize farmers grow landraces, with few farmers cultivating improved varieties (Abate et al., 2017; Ragasa et al., 2013; Van Asselt et al., 2018) even though studies have shown evidence that the new improved varieties, especially the hybrid maize significantly improves productivity (Harou et al., 2017; Mathenge et al., 2014), and its adoption has a positive impact on household welfare and food security (Ali et al., 2020; Jaleta et al., 2018). Ghana needs high-yielding improved maize varieties to increase productivity, ensure self-sufficiency and food security. One of the means of achieving self-sufficiency and food security is by promoting improved maize seeds and encouraging adoption and utilization by farmers.

The literature establishes the use of agricultural innovation system from regional perspectives. For instance, Bergman and Feser, (2001) examined innovation adoption rates at the firm level (enterprises) in Europe using the regional innovation system. We find a close study, that uses the national innovation system in the global south. Specifically, Adetoyinbo et al. (2022) employed the national innovation system using maize as a case study to understand opportunities, constraints, and support systems for bioeconomy in Nigeria from an institutional perspective. Our study is distinct from other studies, in that our study seeks to assess factors that influence the adoption of maize innovations and the dynamic processes that shape such factors. In particular, the study proffers understanding into how maize innovations adaptation happens in the context of interactive social networks. We focus on maize in Ghana, because of its low productivity despite its importance to the country's food security and the economic well-being of farmers. This makes it critical to understand the low adoption of maize innovation to inform interventions towards promoting increased uptake of maize innovations.

This study contributes to addressing the knowledge gap in the innovation adaptation literature by providing an intersectional understanding of innovation processes in their complexities with a target to help inform the design of interventions and promote widespread uptake of innovations. Also, the study adds knowledge to previous studies (Weyori et al., 2018; Gupta et al., 2022) that investigated innovation processes in maize farming systems by identifying specific factors and limitations that influence the uptake of maize innovations. The rest of the article proceeds as follows: the next section (section 2) provides a conceptual framework that underlines the study. Section 3 presents the methodology used for the study. Section 4 presents the findings of the study. In section 5, we present the discussions. The final section (section 6) concludes and offers policy recommendation worth considering.

2. Conceptual framing

In this paper, we conceive the adoption of innovation as a complex interactive process where scientific, technological, and societal systems co-evolve. The conceptual framing for this paper is based on the seminal papers by Lundvall (2007); Lundvall (1992). The study uses the National Innovation Systems (NIS) conceptual framework to understand the interaction between innovation systems, social networks, and the adoption of innovation. The NIS is a dynamic social system characterized by learning through interaction between people (individuals or collective agents) embedded in a social system, with elements of feedback and reproduction during the process of interactions. The NIS theory posits that innovation should be understood as a process, with interactive learning and collective entrepreneurship/social networks fundamental to the process of innovation (Lundvall, 2007). Furthermore, the systems institutional setup and economic structure forms the framework for and affects the processes of interactive learning sometimes resulting in the innovation (Lundvall, 2007). The performance of the system should reflect the efficiency and effectiveness in the production and diffusion of economically useful knowledge. By adopting this conceptual perspective and applying it to a case study in Ghana, the study contributes to a theoretical understanding of interactive learning within a social system and innovation uptake, especially in the global south, which will inform the design of policies relevant to national systems to promote adoption of productivity enhancing innovations. The study draws on the strand of literature (Glover et al., 2019; Leeuwis & Aarts, 2021) that criticizes the notion of adoption as a simple linear individualist model. Glover, (2019) proposes understanding adoption as complex process with multiple factors influencing the innovation process. While Leeuwis and Aarts (2021) further propose that adoption should be assessed as a collective interactional process explained with sociological and institutional dimensions of innovation. We draw on the innovation systems perspective, which views innovation as a complex non-linear process with multiple factors shaping the innovation process (Glover et al., 2019; Hermans et al., 2021; de Oca Munguia, 2021: Leeuwis & Aarts, 2021). Our conceptual framework connects the nexus between innovation systems, social networks, the factors that influence innovation adoption and adaptations.

First, we argue that the innovation system is made up of multiple stakeholders with differential, common and competing interests. New products, new ways of doing things (process), and services are predicated on the reflective processes among all stakeholders (Ankrah & Freeman, 2022). We note and consider in our framework that the adoption and adaptation of an innovation is influenced by farmers demographic characteristics and personal goals, trialability and observability of the innovation, farmers social network and interaction, farmers access to information and extension services, relative advantage of the technology, socio-cultural and political conditions in the external environment to be crucial in shaping the innovation process (Table 1). Farmer's demographic factors (age, gender, education), on-farm factors (farm size), land tenureship, off-farm

Table 1. Factors influencing adoption

Factors influencing adoption	Description	References
Farmer characteristics and personal goals	Farmers socio-economic characteristics and personal characteristics are important factors in the decision process regarding adoption. The knowledge farmers have about a new technology forms the basis of perceptions and attitudes the farmer develops toward the technology.	Assan et al., 2018; Carr & Thompson, 2014; Halbrendt et al., 2014; Lalani et al., 2021; Thierfelder et al., 2017; Halbrendt et al., 2014; Tsige et al., 2020
Trialability and observability of technology	Trialability and observability of a technology provide information on the suitability of a technology and provides opportunity for learning about the potential impact of the technology.	Pannell & Claassen, 2020 Weersink & Fulton, 2020
Farmer's social network and interaction	Farmer's involvement and interaction with social groups and external support provide access to information, enhance social capital, build trust, and can stimulate interest in adopting new technologies.	Streletskaya et al., 2020; Amadu et al., 2019; Weyori et al., 2018; Maertens & Barrett, 2013; Streletskaya et al., 2020
Farmers access to information and extension services.	Quality and quantity of information and support offered to farmers is an important driver of adoption. Extension plays a critical role in communicating information on technology to farmers. Different sources of information are important at different stages of the adoption process.	Say et al., 2018; Nyasimi et al., 2017
Relative advantage of technology	Adoption is influenced by the characteristic of the technology and the context in which they operate. Farmers consider the relative advantage of the new practice over the current practice. Relative advantage is the extent to which an innovation is better than the current system, which depends on the nature of the technology and how it will impact farm profits. Farmers consider the balance between the cost and benefits of adopting a technology.	Brown et al., 2017; Rodenburg et al. 2021; Meijer, Catacutan, Ajayi, Sileshi, Nieuwenhuis et al., 2015)
Sociocultural and political conditions in the external environment	The agroecology, sociocultural, and political conditions in the external environment of the farmer influence the adoption of technology.	Kendall et al., 2022; Shilomboleni, 2020

Source: Authors compiled synthesis from literature.

income, farmers personal values, and needs are important factors in understanding adoption decisions (Assan et al., 2018; Carr & Thompson, 2014; Halbrendt et al., 2014). Farmers tend to adopt a new technology if it better allows them to achieve their personal goals, which can be economic, social, or environmental (Lalani et al., 2021). For instance, farmers who believe and are concerned with conserving the environment are more likely to adopt conservation agriculture technologies and practices (Halbrendt et al., 2014; Thierfelder et al., 2017). Such farmers do not only consider the increase in yields but also the environmental benefits. The trialability and observability of a technology provide information on the suitability of a technology and provide opportunity for learning about the potential impacts of the technology (Pannell & Claassen, 2020).

Second, studies have established that farmer's involvement and interaction with social groups and external support provide access to information, enhance social capital, build trust, and can stimulate interest in adopting new technologies (Streletskaya et al., 2020; Weyori et al., 2018). Farmers with comprehensive and intensive social networks, appear to have greater access to information on specific technologies. Also, farmers awareness of technological innovation is largely determined by their social networks, which can be both informal (i.e. friends, community members) and formal (extension agents and non-state actors). Understanding the influence of social networks on agricultural technology adoption decisions beyond simple information transmission remains critical (Maertens & Barrett, 2013; Streletskaya et al., 2020).

Furthermore, adoption is influenced by the characteristic of the technology and the context in which they operate (Andersson & D'Souza, 2014; Bouwman et al., 2021; Pignatti et al., 2015). Farmers consider the relative advantage of the new practice over the current practice. Where relative advantage is the extent to which an innovation is better than the current system, which depends on the nature of the technology and how it will impact farm profits. Farmers consider the balance between the cost and benefits of adopting a technology (Brown et al., 2017; Rodenburg et al. 2021). Quality and quantity of information and support offered to farmers is also an important driver of adoption. While extension plays a critical role in communicating information on technology to farmers, different sources of information are important at different stages of the adoption process (Nyasimi et al., 2017; Say et al., 2018). Meijer, Catacutan, Ajayi, Sileshi, Nieuwenhuis et al. (2015) emphasize that the knowledge farmers have about a new technology forms the basis of perceptions and attitudes the farmer develops towards the technology. In addition, the agroecology, sociocultural and political conditions in the external environment of the farmer influence adoption of technology.

With many factors likely to influence the adoption process, De Oca Munguia and Llewellyn (2020), highlighted high discrepancies in the consistency of variables used in explaining adoption or non-adoption with neglect of the performance of the innovations or practice and of its interaction with farmers attitudes and preferences. Andersson & D'Souza (2014) further proposed a more thorough analysis of farming households and their resource allocation strategies to understand the farm-level adoption constraints different types of farmers face in the process of adoption in a specific context. Adoption is context specific and dynamic in nature, as such studies need to consider the dynamics between adopters, technologies, and their context (Andersson & D'Souza, 2014).

Adoption has also been evaluated by some authors to evolve in a stepwise manner with components of the agricultural package adopted along the process. Weersink and Fulton (2020) assert that the adoption process involves smallholder farmers becoming aware of a new technology that they consider relevant to their farming operations (awareness stage). Farmers then evaluate the technology by collecting information, assessing its applicability and impacts (non-trial evaluation). Farmers experiment with a new technology on a small scale before first deciding to adopt it entirely or rejecting it (adoption or non-adoption). If there is potential for adoption, the newly adopted technology is reviewed to determine if modification is necessary (revision). Brown et al. (2017) disaggregated the adoption process into phases of exposure, non-trial assessment, trial assessment, and utilization. De Oca Munguia and Llewellyn (2020) provides framework with multiple pathways of changes and adoption along the process. The outcomes of the process of technology adoption are determined by the actions and constraints of both technology and farmers, who are the end-users (Glover et al., 2019).

We apply these concepts (Table 1) in framing our understanding of the factors influencing the innovation processes towards the uptake of maize innovations among smallholder farmers in

Ghana. This conceptual framework provides a guide in understanding the sociological and institutional dimensions of innovation. Specifically, our conceptual framework argues a clear nexus between the agricultural innovation system, social networks, and the factors that influence innovation adoption and adaptation.

3. Methodology

3.1. Study design

Qualitative method is chosen for this study to better explore participants experiences in the innovation process. Qualitative methods analyze data inductively or deductively and have the potential to provide deep insights into understanding the experiences of individuals (Kennedy & Thornberg, 2018; Reichertz, 2013; Thomas et al., 2018). Even though qualitative approach does not allow for the generalization of findings to a wider population, it does provide the opportunity to deeply engage with potential end-users and unpick the factors that motivate, support, or inhibit adoption (Kendall et al., 2022 Bryman, 2016). Participatory methods allow people to speak for themselves, rather than having researchers or development agents speak for them, thereby improving their capacity to influence decisions shaping their lives (Cai et al., 2019). Farmer participatory research generates dialogue between farmers and researchers, considering farmers concerns and conditions and incorporating farmers perceptions and knowledge into the development and testing of new technologies by researchers (Bellon, 2001; Hoffmann et al., 2007). We use participatory research methods to understand the factors that influence the adoption of innovations and the dynamic processes that shape such factors.

3.2. Participants

The study draws on qualitative data collected in two (2) communities in Wenchi Municipal Assembly and Kintampo South Districts. The case study communities were purposively selected to typify major maize growing communities in Ghana. The selected communities had over the past five (5) years received extension services from the Ministry of Food and Agriculture (MoFA) on improved maize varieties. Under the government flagship programme "Planting for Food and Jobs", the government seeks to increase food productivity in the country. The supply of improved seeds at subsidized prices to farmers and free extension services to farmers are major components under the PFJ that targets increasing farmers productivity (MoFA, 2017). Farmers are provided access to improved seeds and complimentary advisory services through their agricultural extension agents. Agricultural extension agents together with farmers in the communities, established demonstration plots in the communities to introduce improved maize varieties to the farmers and encourage the adoption of improved maize seeds.

Purposive sampling was used in identifying farmers who are (1) members of the selected communities and had participated in a Farmer Field School (FFS) intervention that introduced improved maize varieties to farmers; (2) producing maize and principal farmer of the farmland; (3) had at least ten (10) years farming experience and endowed with experiential knowledge about what shapes adoption of improved maize varieties.

To obtain a broad range of perspectives from farmers with diverse characteristics, the selection criteria also included farmers age, sex, level of education, membership of farmer group, land ownership, and accessibility to agricultural extension services, which constitute some key factors that influence farmers adoption decisions. Using these criteria for the selection of participants provided much insight into the diversity of adoption dynamics and furthered the understanding of the complex ways farmers experiment with innovations, and how aspects are taken and applied in different ways. The selection of participants was made with the support of Agricultural Extension Agents (AEAs) from the Department of Agriculture (DoA) operating under the respective municipal or district assembly. Individual in-depth interviews were conducted with fifteen (15) farmers in each of the two (2) selected communities. Between twenty (20) and thirty-two (32) farmers participated in the focus group in each community. Discussions took place in Twi language. The discussions lasted two hours and were held on the field days after the daily activity on the field. The researchers facilitated the discussions with support from the Agricultural Extension Agents. Two (2) research assistants supported with notes taking and recorded the meeting proceedings. Recordings were afterwards transcribed from each focus group into English.

3.3. Data collection

This study draws on field studies conducted between March and December 2021. We draw on observations and data from establishing maize demonstration plots, ethnographic approaches by observing participants daily activities, practices, and interviews exploring the factors that influence adoption of maize innovations and the dynamic processes that shape such factors. And further exploring how maize innovations adaptation happens in the context of interactive social networks. We observed farmers and extension agents' participation in farmer field schools where demonstration plots were established to create awareness of improved maize varieties and to educate farmers on good farm management practices. On each demonstration plot which was about 0.2 hectare, few rows of improved maize varieties (Lake 601,[1] Opeaburo,[2] Obatanpa[3]), and local variety (*Aburoahoma*[4]) were planted on the demonstration plot in the communities on the same plot to compare the local maize varieties and improved maize varieties. Generally, there is a domination of smallholder farmers in Ghana's agricultural landscape, who cultivate small farms. Indeed, Kwapong, et al., (2021) indicated pronounced small farm sizes in Ghana. Field days were organized at different stages in the growth of the maize plants on the field, where farmers were invited to the demonstration plots to observe the growth of the plant and to share their observations. Field days were organized at planting, NPK fertilizer application (about 2 weeks after planting), Urea application (about 5 weeks after planting) and harvesting stages. At each field day, in-depth discussions were held with farmers to give extensionist feedback on farmers perception of the varieties and lessons learnt. This platform also provided an avenue for farmers to reflect on their farming activities, to ask questions, and for the extensionists to know the concerns of farmers and address such concerns. Also, to evaluate instances of learning and uptake of practices.

To gather data, we used a combination of focus group discussions and individual in-depth interviews. One-on-one interviews were conducted with participants who had participated in farmer field school and demonstrations where improved maize was introduced to farmers. Such farmers were familiar with the improved varieties and gave an account of their experience with improved maize varieties. We used narrative interviews in documenting farmers experiences. Narrative interview is a form of qualitative research method that uses narrations to elicit information on personal experiences from the informant with a detailed focus on events and actions, making reference to place and time (Kwapong et al., 2020; Muylaert et al., 2014). Farmers experiences narration were guided by the following themes as outlined in the conceptual framework (Table 1): (1) farmers characteristics and personal goals, (2) trialability and observability of technology, (3) farmer's social network and resources, (4) relative advantage of the technology, (5) Farmer's access to information and extension services and (6) sociocultural and political condition in the external environment. Farmer focus group discussions focused on understanding farmers practices before the introduction of the innovations, farmers interaction with the introduced maize innovations, approaches or methods used for the farmer field school, awareness creation, knowledge transfer processes and learning, process(es) of uptake of the innovation, how farmers social interaction influenced uptake of the innovation, factors influencing uptake of innovation, constraints to uptake of innovations, farmers opinion on what works to encourage uptake of innovations.

We observed the COVID-19 protocols by providing nose masks for use by all farmers and researchers during the focus group and individual interviews and ensuring social distance and spacing sitting arrangements. We also provided hand sanitizers for use by the researchers and farmers.

3.4. Data analysis

For the data analysis, the recorded narratives from the interviews and focus group discussions during the field days were transcribed from Twi into English. We also wrote notes on direct observation from the fields. The field notes were transcribed, and the text was paraphrased, and key words or codes were identified and clustered. First, order coding based on the identified themes from the literature review was used in clustering the information. We also examined the transcripts for possible additional categories (Fereday & Muir-Cochrane, 2006). Content analysis was done where information with similar themes was grouped into clusters and identified patterns (Krippendorff, 2018,). Content analysis is a qualitative research method that aims to provide knowledge, new insights, a re-examination of facts, and a guide for action (Elo & Kyngäs, 2008). The Nvivo 12 software was used for analyzing the data, where we identified major and sub-themes, following a previous study by Ankrah et al. (2021). We checked the outcome of the content analysis and emerging themes to assess consistency with other findings discussed in the literature. We then formed conclusions based on our interpretations of the data.

4. Results

Following the conceptual framework, the results are focused on providing insight into understanding the factors that influence the adoption of maize innovations and the dynamic processes that work in shaping such factors. Integrated throughout the presentation of the results, we highlight how farmers experience maize innovation adaptation in the context of interactive social networks using the case of farmers involvement in farmer field schools and field days.

4.1. Farmers access to information and extension services

Extension plays a crucial role in providing information to farmers on the available improved varieties and planting protocols. Agricultural extension agents serve as a link between the researchers and farmers in transferring technologies to the farmers, creating awareness and encouraging utilization by farmers. Five (5) field days were organized where farmers attended and participated in activities on planting, NPK fertilizer application, Urea application, monitoring, harvesting, and evaluation of the maize hybrids.

Participants during group discussions and individual interviews highlighted numerous benefits of creating awareness of the improved varieties (Box 1). Awareness creation on the improved maize varieties centered on making farmers understand the benefit of planting a high-yielding variety to increase farmers income (Box 1; i). Farmers want to experiment with new variety, observe and compare the performance of the newly introduced variety and compare to their existing varieties (Box 1: ii). This information will inform their future decision-making on the variety to plant. Farmers learnt farm management practices such as plant spacing and planting in lines (Box 1; iii), applying fertilizer at the recommended rates (Box 1; iv), controlling for maize pests and diseases (Box 1; v).

Box 1: Examples of farmers perceived benefit of awareness creation on improved varieties.

(i) I did not know of hybrid maize until I participated in this farmer field school. I now know that the improved varieties have a higher yield which will give me a higher income (FGD/Wenchi/July 2021).

(ii) We farmers want to see the performance of the new variety to compare with our local variety. If the yield is good, we can consider planting the new variety (FGD/Wenchi/April 2021).

(iii) I learnt how to lay out the maize field and plant in lines to provide the benefit of increasing plant population on my field to have a good yield (FGD/Wenchi/July 2021).

(iv) I have learnt that if I plant maize and I want a high yield, I will have to apply fertilizer at the recommended rates to obtain optimum yields (FGD/Kintampo South/July 2021).

(v) From the farmer field school, I have learnt planting protocols for different maize varieties and management practices including how to control Fall Armyworm pests which will help in my maize farming (FGD/Kintampo South/July 2021).

These findings show that a lot of learning and knowledge transfer happens during awareness creation on innovation to farmers. These benefits to the farmers are applied by farmers in their fields even if they do not end up planting the improved maize variety promoted. For instance, farmers learn the proper way of applying fertilizer on their fields, how to control pests and diseases, how to control weeds, planting according to recommended spacing.

4.2. Farmers personal characteristics and personal goals

Farmers socio-economic characteristics and personal characteristics are important factors in the decision process regarding adoption. The knowledge farmers have about a new technology forms the basis of perceptions and attitudes the farmer develops toward the technology. Farmers who had heard about the benefits of planting improved maize seeds or had the experience of planting maize seeds and knew the benefits of the improved seeds had a positive attitude towards planting the introduced improved maize seeds. Such farmers were quick to share their experience and knowledge with other farmers during field days group meetings and encouraged other farmers to adopt the improved seeds (Box 2; i). Farmers who had indicated that they had set personal goals of increasing their yields and consequently their income, were interested in trying the improved variety (Box 2, ii). During field observations in the minor seasons, we observed that farmers who had planted the improved varieties introduced to them during the farmer field schools owned the land on which they planted. Such farmers indicated they wanted to try out the seeds on their land and see how the improved varieties performed on their soil before deciding to plant on the entire field (Box 2, iii). This implies that trialability and observability of the innovation provide information that guides farmers decision on the suitability of innovation and provides an opportunity for learning about the potential benefit of the technology.

Box 2: Examples of farmers statements on personal characteristics and personal goals

(i) " I bought Lake 601 maize seeds from the extension officer and planted it last year. He advised me on the planting protocols, and when I planted according to the recommended spacing and applied fertilizers, I had a very good harvest, more than three times what I use to harvest. I encourage you all to plant improved seeds" (KII,Male/Kintampo South/November 2021).

(ii) "I want to increase the yield of my maize plant and gain more income from sales of the grains. I am therefore willing to invest some money in buying the improved seeds and needed input to increase my yield (KII,Male/Kintampo South/November 2021).

(iii) I wanted to try out the new variety on a portion of my own plot and see how it will perform in my field. This will inform my decision on the proportion of my field that I will use to plant the improved seeds (KII, Male/Wenchi/November 2021).

We however, observed that, for farmers who were not planting the improved varieties during the farm visits, they mostly indicated that they preferred to plant their local varieties, or that they did get access to the seeds in time to plant or did not have the money to acquire the inputs. Such constraints limit farmers uptake of improved seeds. Most smallholder farmers are resourced constraint, and frugal with the use of money. Hence, they prefer to use their own maize seed source, which they keep and plant in the subsequent farming seasons. The improved seeds, however need to be purchased during each planting season, pointing to financial requirements associated with the improved seeds.

4.3. Trialability and observability of technology

In several interviews, farmers who indicated that they planted improved maize varieties explained that they first experimented on a small piece of their farmlands and based on the superior performance observed, decided to expand on their farm lands. The farmers statements included;

" When you plant a new variety, you first want to try out on a small piece of land first and observe the performance. If you plant a large portion of your field with a new variety and it does not perform well you will lose much" (KII, Male/Wenchi/November 2021).

" It is risky to plant your entire field with a new variety. You would not know how the maize plant would perform in the new environment" (KII,Female/Kintampo South/November 2021).

From the field observations, we noticed that farmers who tried planting the improved varieties on their fields, they first experimented or planted the improved varieties on a smaller portion of their field to observe the performance of their field. This indicates that in the adoption process, after the awareness and knowledge acquisition of an improved technology, farmers may want to perform a trial of the technology to evaluate the performance of the innovation to inform their decision towards adoption of the technology. The trial stage, therefore, plays a critical role in the adoption process.

We also observed that, farmers who had participated in the establishment of the maize demonstration plots during the major planting season applied some of the management practices on their fields during planting in the minor season. For example, we observed that some farmers planted their maize fields in lines during the minor season. Such farmers indicated that they previously did not plant their fields in rows. Some farmers also indicated their intention to plant their fields in lines following the recommended spacing and fertilizer application rates on their fields in the next major planting season. Such farmers indicated that they have observed from the demonstration plots the performance of the improved varieties and were convinced to try out the improved varieties to increase their yield. This shows a positive instance of adoption of some practices as part of the adoption process. Even though some farmers are not planting the improved maize varieties, they decided to follow the recommended practices anticipating that their yields would increase. Such farmers were taking on aspects of the technology introduced to them.

Fertilizer application introduced to farmers included the application of NPK fertilizer at 2–3 weeks after planting and Urea application 4–6 weeks after planting. It was observed that farmers did not follow the recommended fertilizer application rates. Some farmers skipped the second week application and applied either NPK or a combination of urea and NPK during the 5th week. Even though the extension agents taught the farmers to make double applications of fertilizer, farmers in practice applied the NPK and Urea at different times or sometimes mixed the two fertilizers and applied them to their fields at different times, which differed from the practice that was taught to them by the extension agents. This shows that even though farmers acquired and used the knowledge transferred to them, in actual practice, they did apply this knowledge differently, adapting it to their local context. Farmers rationale for combining the NPK and urea was to save cost and have a one-time application than a two-time application which will require much cost and time. Also, in the application of the fertilizer, farmers method of application was broadcasting or spreading the fertilizer all over the field, while the extension agents taught farmers to practice deep placement by burying the fertilizer in the soil. This practice taught, differed from the practice actually implemented by the farmers even though they got the message of applying fertilizer on their fields. This result shows inconsistency in what is taught to farmers and how farmers choose to put into practice what is taught to them.

4.4. Relative advantage of the innovation

Farmers consider whether there is a relative advantage of the new practice over the current practice. Relative advantage is the extent to which an innovation is better than the current system, which depends on the nature of the technology and how it will impact farm profits. Farmers compared their local maize varieties to the introduced improved varieties. Farmers explained that their local maize variety had slender cobs, filled with many grains. For their local variety, the yield was good even with little rains. Also, the grains when milled, had very little chaff. Hence, farmers preferred an improved maize variety that had similar traits to that of their local maize variety. For example, during a field day at harvesting, farmers explained that for the cob and grain characteristics, farmers prefer cobs that are long and slender with maize grains that are small and fully fill the cob length to the tip (Box 3; i). Farmers consider the balance between the costs and benefits of adopting a technology. Farmers indicated that they would prefer varieties that have very high yields as well as the variety that is early maturing (Box 3; ii). With the changing climatic conditions with long periods of drought, farmers mentioned that they preferred early maturing maize varieties. Farmers however, indicated that it is more expensive to plant the improved varieties as farmers incurred more cost in acquiring the improved and additional inputs such as fertilizers required to optimize yield (Box 3, iii).

Box 3: Examples of farmers evaluation of improved varieties

(i) "Lake 601 is long and slender, the gains are small, filled to the tip and looks just like our local variety. When you shell the gains, you will get a lot of grains" (FGD/Wenchi/July 2021).

(ii) "Even with the little rains, the improved varieties like Lake 601 and Opeaburo grow very fast and yield more compared to our local variety" (FGD/Wenchi/July 2021)

(iii) It is more expensive to plant the improved varieties. You have to buy the improved seeds and also buy fertilizer to apply on the field, which will increase your cost of production. If you are lucky and the yield is good, then you can recover your cost and make some profit (FGD/Wenchi/July 2021).

This finding shows that in the adoption process, farmers evaluate the new innovation relative to the old practice. Farmers will prefer a new technology with similar or better performance than their current practice or technology. And in this evaluation, they consider the balance between the cost and benefits of adopting a technology.

4.5. Farmers social network and interaction

Farmers explained that most of them were in farmer groups and that the extension agents had supported them in forming the farmer groups. Through their groups, they were identified to participate in the farmer training programmes organized by MoFA. Extension agents preferred to work with farmer groups as it was much easier to organize the farmers through groups. Farmers indicated that they became aware of the improved maize varieties through their groups and peer farmers.

"Our farmer group members managed the demonstration plots. We had our meetings afterwards. We had the opportunity to ask all questions that bothered us, and extension agents responded to our concerns. The extension agents brought us improved seeds and inputs when they came for the field days" (FGD/Wenchi/July 2021).

At group meetings, improved seeds were introduced to farmers. Farmers had access to improved seeds through their groups and the opportunity to participate in group activities such as trainings and farmer field schools which helped farmers improve their activities. Group meetings provided the opportunity for extension agents to address farmers concerns and market their improved seeds. Farmers interacted with other fellow farmers and learnt from each other. Farmer's involvement and interaction with social groups and external support provide access to information, enhance social capital, build trust, and can stimulate interest in adopting new technologies.

4.6. Sociocultural and political conditions in the external environment

The agroecology, sociocultural and political conditions in the external environment of the farmer influences adoption of technology. Farmers indicated that, with the changing climate where there are erratic rainfall conditions that makes it difficult to predict the timing of the rains, planting early maturing maize seeds and drought-tolerant varieties is crucial (Box 4; i). Farmers who indicated having planted the improved maize seeds often indicated that they delayed in planting with the onset of the rains early in the planting season and hence went in for the early maturing maize varieties as they had missed few rains early in the season (Box 4; ii).

Box 4: Examples of farmers statement on external environment on their use of improved maize seeds.

(i) Now that the weather is changing, if you don't plant early maturing variety and the rains delay or stop earlier in the season or there is not much rainfall, then you lose all your plants due to drought weather conditions (KII,Male/Kintampo South/November 2021).

(ii) I planted late in the season, so I decided to plant the early maturing variety. With the improved seeds, even with little rain, it will still survive and do well (KII,Female/Kintampo South/November 2021).

Farmers however raised concerns about the viability of the improved seeds, due to the long delays in getting the seeds to the farmers. Farmers receive improved seeds through the Agricultural Extension Agents or from the agro-input shops in town. The Agricultural Extension Agents (AEAs) do not sometimes supply in time to the farmers. Farmers indicated there are sometimes delays in the release of the seeds. Farmers, therefore, resort to their saved seeds when they are unable to get the improved seeds in time. Farmers continue to plant their saved seeds, and use their old ways of planting maize which makes changing to take on new practices difficult. Farmers are more convinced to take on new practices when they witness other fellow farmers fields having planted improved maize seeds and getting a good harvest. An experience sharing from such successful farmers encourages the uptake of the improved varieties by farmers who continue to plant landraces.

5. Discussions

Unlike many studies that view adoption as a simple linear model with adopters and non-adopters, few studies focus on understanding the innovation process and the many instances of learning and changes that happen during the adoption process. The few studies that have focused on understanding the adoption process have described adoption as a continuous process, not solely a product with a binary outcome (Glover et al., 2019; Hermans et al., 2021), adoption as often not being complete or partial or having aspect or component of the innovation taken or experimented with (Andersson & D'Souza, 2014). Also, adoption is to be assessed as a collective interactional process explained with sociological and institutional dimensions of innovation (Leeuwis & Aarts, 2021). Further, adoption happens in a stepwise manner, with some steps happening before the others (Brown et al., 2021; De Oca Munguia & Llewellyn, 2020), and the ways individuals experience innovation happen in flexible ways and keep changing over time, adapting to individual context.

The challenge with understanding adoption originates from defining adoption as a binary choice option with adopters and non-adopters without providing clarity on understanding the adoption process and what shapes the innovation process. In this paper, we conceive the adoption of innovation as a complex interactive process where scientific, technological, and societal systems coevolve. We draw on the innovation systems perspective, which views innovation as a complex non-linear process with multiple factors shaping the innovation process. We use an empirical approach to understand the different ways in which farmers experiment, take and use maize innovations. We investigate the factors that influence the adoption of maize innovations and the dynamic processes that shape such factors. Also, understanding how maize innovations adaptation happens in the context of interactive social networks. The main themes identified from this study were: (1) farmers characteristics and personal goals, (2) trialability and observability of technology, (3) farmer's social network, (4) relative advantage of the technology, (5) farmers access to information and extension services and (6) sociocultural and political condition in the external environment.

The findings from this study support research studies conducted in understanding the instances of learning and knowledge transfer during the innovation process (Bouwman et al., 2021; Glover et al., 2016; Hermans et al., 2021). The findings reveal that a lot of learning and knowledge transfer happen among farmers and from the extension agents through awareness creation, the trail of the improved maize varieties on farmers' fields, and evaluation of the introduced innovation before deciding on the adoption of the innovation. During farmer field schools and field days, farmers learn various farm management skills and have some of their farming challenges addressed. Farmer exchange experiences and share knowledge with fellow farmers, which results in the generation of interest and application of new skills and encourages the adoption of new technologies. Studies have shown farmers access to advisory services from agricultural extension agents, and from peer farmers had the potential to scale up the adoption of improved technology and increase farmers productivity (Ahmed & Anang, 2019; Kwapong et al., 2020; Martey et al., 2020). The knowledge gained from farmers is applied by farmers in their own fields, sometimes even for other crops, even if the farmers do not end up planting the improved maize varieties promoted. These instances of learning are often neglected in the evaluation of the adoption of innovation, even when such knowledge gained is a positive benefit gained from the introduction of the innovation. This finding support research studies that argue that adoption should not be only measured as a binary option with adopters and non-adopters but to consider the instances of learning and knowledge that happens during the adoption process with positive unintended consequences. A cumulation of many instances of learning and knowledge uptake could be considered a positive impact on adoption even if the technology or innovation is not in use by the farmer at the time of evaluation.

This study finding also shows that in the adoption process, farmers evaluate the new innovation relative to their old practice. Farmers will prefer a new innovation with similar or better performance than their current practice. And in this evaluation, they consider the balance between the cost and benefits of adopting a technology. Weersink and Fulton (2020) noted that profit considerations are clearly important, particularly in the later stages of the adoption process and further indicated that such profit considerations should be supplemented with other social considerations early in the process when farmers come into contact with the innovation.

The findings from the study also revealed, there is inconsistency in what farmers are taught and the practice of what is taught to the farmers. Even though farmers utilize the technology such as the application of fertilizer to their crops on their field, the rate of application, method of application, and timing of application is carried out in a different way from what was taught to them. This plausibly might be based on the fact that farmers possess indigenous knowledge that they tend to apply to science-based technologies even though their indigenous knowledge-base is often relegated to the background. Ankrah et al. (2022), however, advocated for integration of farmers indigenous knowledge into science-based approaches. Farmers mostly adopt components of the technology and apply them based on their local conditions or context and also consider the cost and benefits of the utilization of the technology. Understanding farmers local context is important in encouraging the uptake of new technologies. This finding points to the fact that farmers self-innovate based on rational choices and the need to be economical. Indeed, Ankrah and Freeman (2022), and Ankrah (2022) give credence to this finding.

Farmers social networks played a crucial role in providing farmers access to improved seeds and trainings to learn about new farming technologies. Group meetings provided a window of opportunity for extension agents to address farmers concerns and provide them access to improved seeds. Farmers interacted with other fellow farmers and learnt from each other. Leeuwis and Aarts (2021) argue that adoption must be regarded as a collective rather than an individual process. Farmer's involvement and interaction with social groups and external support provide access to information, enhances social capital, builds trust, and can stimulate interest in adopting new technologies (Dolinska & d'Aquino, 2016; Skaalsveen et al., 2020; Weyori et al., 2018).

The knowledge farmers have about a new technology forms the basis of perceptions and attitudes the farmer develops toward the technology. Such intrinsic factors have been less studied in the broad adoption literature, even though such internal decision-making processes play a vital role in the process of uptake of innovation (Meijer, Catacutan, Ajayi, Sileshi, Nieuwenhuis et al., 2015; Negatu & Parikh, 1999; Shikuku, 2019; Zossou et al., 2020).

6. Conclusion and policy recommendation

This study assesses the factors influencing the innovation processes toward the uptake, and adaptations of maize innovations among smallholder maize farmers in southern Ghana. The findings show that substantial learning and knowledge transfer typically happen during the awareness creation phase in the innovation process. Farmer field schools, interactions with fellow farmers, and agricultural extension agents constitute the main effective conduits for awareness creation on maize innovations. These conduits shape farmers decision-making regarding experimentation or uptake of an innovation. The innovation processes are intertwined with instances of reflective and accidental learning, often neglected when evaluating the adoption of innovations. The study finds that in the innovation process, farmers evaluate new technologies relative to their old practice, considering the cost and benefits. Farmers prefer new innovations with similar or most instances, superior performance. The findings further revealed inconsistencies in what farmers were originally taught and what they eventually practiced. Specifically, we find adaptations to suit contexts. The adaptations point to the fact that farmers self-innovate, and tend to have knowledge and resources that help them to bring on board new products, and processes. The implication is that both adopters and non-adopters' knowledge-based and resource mobilization abilities should be harnessed and not be relegated to the background. In particular, emphasis should be paid to the complex processes, negotiations, and contestation that leads to innovations within and across adopters and non-adopters. Farmers become more convinced to take on new practices when they interact with other peer farmers and witness other fellow farmers' implementing new innovations in their fields. Experiences shared from progressive farmers encourage the uptake of the new innovations.

In summary, the findings show many instances of learning, knowledge transfer, uptake of practices, and innovation adaptations happening among smallholder maize farmers during the innovation process. The innovation process is shaped by farmers characteristics, personal goals, trialability of technology, social network, relative advantage of the technology, access to information and extension services, and sociocultural conditions in the external environment.

We suggest that, in understanding adoption, the focus should be directed on understanding the intricate innovation processes, embodied in an interactive social network, with many instances of deliberate reflective learning and co-creation of knowledge. It is important for agricultural programmes to be flexible to accommodate unplanned innovation adaptations in ensuring sustainable agricultural development. This should inform the continuous design of agricultural programme interventions to promote the widespread uptake of innovations. Farmer field schools and field days should be further explored to promote maize innovations among farmers. We encourage the public agricultural advisory and extension services to target peer farmers as an effective conduit for agricultural extension delivery, particularly against a backdrop of the deficit of agricultural extension agents to farmer ratio. Most countries in Sub-Saharan Africa can consider peer farmers to harness the benefits to bridging the gap in extension delivery.

6.1. Limitations of study

The limitation of this study has to do with the sampling of respondents which was purposive rather than random sampling, and the results presented are based on the case experiences of the selected farmers in two communities which limits the generalization of the findings. We used triangulation of information combining multiple sources (one-on-one interviews with selected farmers, focus group discussions and direct observation of farmers practices) to increase the credibility and reliability of the results.

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Notes

1. Lake 601 is a hybrid maize released by South Africa. It has a yield potential of 9Mt/Ha.
2. Opeaburo is a top cross hybrid maize released by the Council for Scientific and Industrial Research—Crop research Institute (CSIR—CRI). The variety has a potential yield of 7.5 t/ha and matures in about 110 days.
3. Obatanpa is an open-pollinated variety released by the Council for Scientific and Industrial Research—Crop research Institute (CSIR—CRI). The variety has a potential yield of 4.6 t/ha and matures in about 110 days.
4. Aburoahoma is a landrace/local variety with a yield potential of about 2–2.5 t/ha and matures in 120–130 days.

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