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Sustainability of agriculture extension services in the face of COVID-19: A study on gender-specific market systems

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Abstract: In the fourth industrial revolution, achieving sustainable agricultural development while feeding a growing world population and maintaining a balanced interrelationship between the economy, society, and the environment has been a significant challenge. However, COVID-19 disrupted agricultural extension and advisory systems, affecting all market participants. The complexity of the pandemic has impacted the private sector, public sector, extension staff, donor funding, education, and research systems, subsequently affecting human nutrition. This paper aims to expertly review COVID-19's effects on the sustainability of gender-specific agricultural extension service systems. Demand and supply market stakeholders in the extension system are thematically discussed. The findings reveal various consequences of COVID-19 for market actors on both the demand and supply sides of the extension system. Private-sector players often support expansion directly or indirectly, with multi-sectorial support and funding strategies

ABOUT THE AUTHOR

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Enock Siankwilimba, a seasoned agricultural market system development expert with over two decades of experience, has contributed to numerous donor-funded extension programs and projects in Zambia. He is a founding member of Musika Development Initiative Zambia Limited, where he currently serves as a consultant and technical advisor. Additionally, Enock is a PhD student at the University of Zambia's Graduate School of Business Studies, focusing on developing a sustainable cattle business model for small-scale cattle farmers in Namwala District, Zambia, utilizing a systems-dynamic approach. His research interests encompass agricultural market system development, livestock and crop business models, climate change, value chain development, and rural agricultural extension development.

PUBLIC INTEREST STATEMENT

Agriculture faces complex challenges hindering its growth and global food production due to the ever-growing population. Women and youth significantly contribute to food production and have been disproportionately affected by these challenges. Creating gender-specific markets to promote inclusive and sustainable development has been a persistent challenge for international and national organizations.

Employing agricultural extension service systems to stimulate the growth of women and youth in agriculture received support, but COVID-19 disrupted this effort. This paper explores the literature on the sustainability of agriculture extension services amid COVID-19's impact on gender-specific market systems in developing countries. The study's results are crucial for policymakers, academics, and program implementors involved in agricultural market development worldwide.

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existing for sustainability. In many developing nations, the comprehensive extension system was disrupted by COVID-19, impacting household incomes and nutrition. The pandemic accelerated the adoption of digital technologies in many developing nations, transitioning from a centralized to a decentralized and pluralistic extension model. Multi-sector coordination and execution, especially from health and other sectors, are crucial in managing complex crises that disrupt the market system.

Subjects: Agricultural Development; Agriculture and Food; Agriculture & Related Industries

Keywords: COVID-19; agricultural extension; sustainability; smallholder farmers; market players; gender market systems

1. Introduction

In the current fourth industrial revolution, achieving sustainable agricultural development is one of humanity's greatest challenges due to the increasing global population and the need to balance between preserving and maintaining a dynamic interrelationship between the economy, society, and the environment in the face of natural and human-induced calamities. Since time immemorial when agriculture was first domesticated, humans have encountered various difficult problems and only solved some of those effectively (Ahmad et al., 2020). Agricultural extension systems were meant to help pass on technical information and products from suppliers to the farmers to help them improve their production and productivity.

Over the past several decades, system thinkers have employed strategies to identify long-term solutions to various interrelated agricultural complex problems that impede human development, even amid well-designed extension delivery systems. Recent years have seen a consensus among researchers that studying the underlying causes of agricultural problems should not be done in silos but should instead call for the application of the entire systems that create them (Yasobant et al., 2020). It is evident that solving one issue in the agricultural sector ultimately results in the creation of another one that is surprisingly complex and eventually affects the weakest in the market, such as women and youths found in developing countries.

After any stress or shock, there are numerous approaches to evaluating the community market system, including a multidimensional tool that measures multi-level market resilience (Choptiany et al., 2021). Levine et al. (2017) and Choptiany et al. (2021) employed GOAL Global's international development and humanitarian interventions framework called Resilience for Social Systems (R4S) to analyse the resilience of socioeconomic systems which concentrate on causes and examples of risks. The Mercy Corp's Strategic Resilience Assessment tool, STRESS, and most recently, Market Systems Resilience Index (MSRI) analysis, which essentially analyses the market system's resilience after any stress exposure.

According to some academics, researchers and development experts do not focus on the right issues, preventing business and development players from developing the appropriate sustainable solutions (Sterman, 2002; Sterman & Sweeney, 2007). Challenges in agriculture rarely wait for one to end before striking again. The challenge facing women and youth in the agricultural markets remains. That is, addressing the systemic challenges in the designed solutions regardless of geographical, agroecological, ethnicity, and, more importantly, cultural orientation. The systemic challenges seem to thrive well when there are already existing challenges, thereby creating a challenge trap cycle. A "challenge complexity trap cycle" can occur when challenges repeatedly pose as unresolved issues while concealing the long-term sustainable solutions to address them.

The focus of this inquiry was to conduct a literature review assessment on the effects of COVID-19 on the sustainability of agricultural extension service systems on the smallholder gender specific market. The market systems approach guided the review. Other specific objectives of this study were to review digital agriculture in response to COVID-19, the effects of COVID on Women in Agricultural Extension, nutrition integration in agriculture extension service systems, and understanding sustainable enabling agricultural extension service provision.

2. Data and approaches

The sustainable agricultural extension service systems in the gender specific market systems used data from studies published in peer-reviewed journals and grey literature on developing countries between 2019 and 2023 to assess the sustainability of Agricultural Extension Services in the face of COVID-19, using gender specific extension market systems. To achieve formidable results, the search for "sustainable agricultural extension services" in "developing countries" and"effects"of"COVID-19 sustainability/sustainable extension services" "and gender market" in "different countries" in Google Scholar, Springer, and Scopus was undertaken. This search returned 130 articles published between December 2019 and October 2023. Additionally, for the COVID-19 pandemic, the search narrowed the analysis to include 2019–2023 studies focusing on the effects and ultimately excluded all the articles that were not aligned with the study.

A theoretical framework for the market systems approach was used to guide the study. One limitation of this study is that it was biased towards developing and less toward developed countries which acted as an inclusion and exclusion criteria to fit into a limited study space. Secondly, although aligned, the methods used for review did not follow the standard systematic review or discourse analysis approaches. Instead, a review of only the primary studies on the effects of COVID-19 on the sustainability of agriculture and extension systems in developing countries published between December 2019 and October 2023 was undertaken.

3. Theoretical perspectives of gender-specific extension systems and COVID-19 effects

Various methods have been used over the years to understand the participation of smallholder farmers, especially women, in agricultural development through the extension delivery system. The donor community has used the market system approach to sustainably incorporate market players in agricultural development, especially for marginalized rural poor. For example, Mutambara (2015) used the market systems approach to understand the underlying causes of the low uptake of irrigation among smallholder farmers in Zimbabwe. He deduced that the approach was holistic and inclusive in improving the long-term viability of smallholder irrigation schemes.

The market systems approach gives rise to the market being inclusive, the core, which is demand and supply, being functional and incentivising both the suppliers of the products and services and the producers or buyers. One goal is to encourage private-sector players to take the lead in serving smallholder farmers, particularly women and youth who are critical players but yet so little is known and reported about them (Mphande et al., 2023). While the government provides an environment to support sustainable extension provision services, there is a lack of reporting on gender-specific agricultural market development. These services and products offered should be accessible, affordable, and, where possible, utilizable by consumers.

The interlink between accessibility, availability, and affordability gives rise to the sustainable development of the market system in which women and youth can interplay with elders and reduce discrimination. However, research has found that COVID-19 affects the positive interdependence of the market system in its core function, producing unintended results. The rules and regulations governing the market system impact the functionality of the core market in providing equitable extension services for all. According to reports such as Rahmandad and Sterman (2022), COVID-19 has impacted rules and policies governing extension services provision and consumption in market ecosystems.

In this regard, COVID-19 replaced the standard rules previously governing market players in the delivery of extension service systems by introducing new ones. Social distance, masking up, quarantine, lockdown, and sanitizing drastically affected the flow rate of information and products from the extension service providers to the farmers, reducing productivity and production at the farmer and national levels in many developing countries. Alvi et al. (2021) reported that women and youth were highly excluded from accessing extension services in India due to COVID-19.

3.1. Sustainable and inclusive agriculture extension business models

International organizations have focused their attention on developing inclusive and climate-resilient sustainable agriculture extension business model systems for several years (Amoussohoui et al., 2022). In providing globally workable, responsive, inclusive, and sustainable extension and product delivery systems, sustainable agriculture business models utilise information delivery systems that transmit technical and scientific knowledge from upstream extension firms and officers to farmers in the field to ensure that the environment remains habitable for future generations of farmers and agricultural workers (Sterman & Sweeney, 2007). Achieving this goal has been challenging for centuries across generations. For example, extensive research demonstrates that current agricultural business extension strategies are biased to benefit more male farmers than female and young farmers due to the traditional and cultural features of communities in developing nations (Machina & Lubungu, 2019; Mutale & Li, 2021). Women and youth in developing countries, where most of the population relies on agriculture for their livelihood, suffer disproportionately from the negative effects of current economic models. While failure to deliver sustainable information and products to market players has been blamed on climate change and technology.

Recent studies have shown that COVID-19 has also played a critical role in leading to low agricultural production (Siankwilimba et al., 2021, 2022). As a result, COVID-19 emerged worldwide to amplify the detrimental effects of low agricultural productivity and production, limiting the possibility of achieving the agreed-upon sustainable development goals by 2030 (Siankwilimba et al., 2021, 2022). Mutale and Li (2021) revealed that while the different sustainable development goals were expected to be met by 2030, the outbreak of COVID-19 in China and which subsequently spread rapidly across the world, stressed not only the health systems but also the economic, social and environmental systems that sustained the agricultural extension systems. According to Siankwilimba et al. (2023) and Shokati Amghani et al. (2023), the sustainability of agricultural extension systems that benefit the gender-specific market, as outlined in the sustainable development goals, depends on these economic, social, and environmental issues. Shokati Amghani et al. (2023) found that agricultural extension models, when combined with sites, enhance value addition, especially for women farmers who are predominantly engaged in food production, as indicated in Figure 1.

Prayitno et al. (2023) carried out a study to evaluate the quality of life (QOL) and food security in the face of COVID-19 in Indonesia using traditional extension models. The results indicated a strong correlation between QOL and food security, with the most significant material variable having an 80% effect. The results further showed that government extension programs that reduce hunger risk and enhance quality of life, especially for women and youth, were implemented to advance food security at the village level.

Prayitno et al. (2023) and Maulu et al. (2021) attributed the high exclusion of women during economic shows to poor extension service delivery models in most developing countries. It is worth noting that poor extension models lack market attractiveness incentives which tend to exclude women and youth, as shown in Figure 1.

Alvi et al. (2021) suggested that extension has a crucial role in minimizing the effects of COVID-19 on the female agriculture market in addition to health-related interventions like immunizations (Mwiinde et al., 2022; Prayitno et al., 2023). Alvi et al. (2021) demonstrated that COVID-19-related

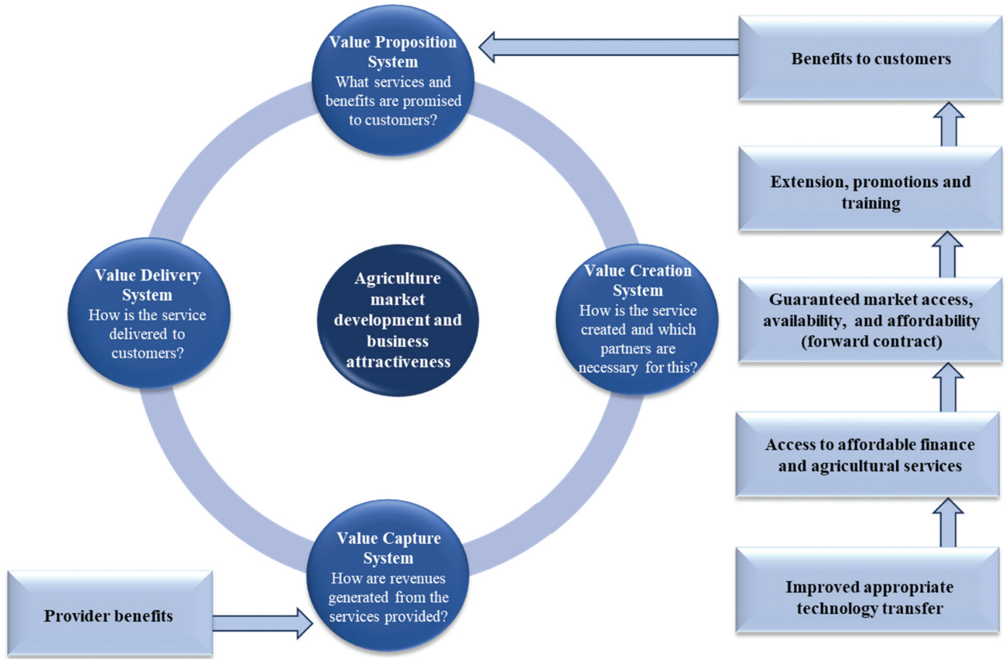


Figure 1. Gender-specific agricultural market attractiveness and unique value proposition for inclusive sustainable extension growth for all market players inclusive of women and youths (authors attribution and computation).

hunger can only be reduced once the market becomes attractive by highlighting advantages for different levels of product and service providers through the use of improved sustainable extension services. Figure 1 demonstrates that all market participants have access to extensions, promotions, and training, along with a contracted or guaranteed market. Additionally, it enables the integration of a distinctive value proposition into the market development process for all participants, particularly vulnerable groups like women and youth, who spend much of their time tending to the land in developing nations. Therefore, a person's view of their quality of life (QOL) is based on their objectives, expectations, standards, amount of independence, social connections, self-confidence, and interactions with their surroundings free of diseases such as COVID-19 and extension models fostering agricultural development (Prayitno et al., 2023).

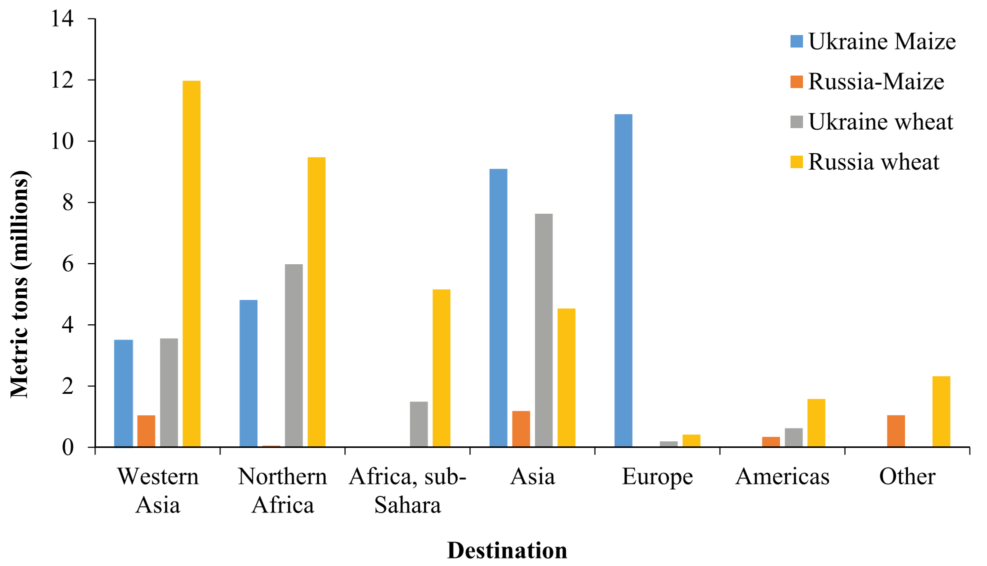
3.2. Effects of COVID-19 on input and markets

Both the input and output markets are moving in lockstep. Smallholder farmers, for example, have suffered disproportionately from increased local food and input prices since the commencement of COVID-19. According to research, the conflict between Russia and Ukraine has aggravated this because of the low affordability of fertilizer, as assessed by the price ratio of food to fertilizer (Montanarella & Panagos, 2021). The fact that 2022 was anticipated to be the year of greatest demand for rice and maize and that Africa would be the world's top grain importer, for example, raised serious and grave concerns (FAO and WFP, 2022). According to FAO and WFP's (2022) research, governments spent over US$710 billion in subsidies, including over US$380 billion in response to food, gasoline, and fertilizer price increases to provide social safety measures for 1 billion people. Maredia et al. (2022) and Gentilini (2022) submitted that low-income countries spent around US$4.3 billion on social security, whereas high-income countries spent US $507.6 billion.

Further, the conflict between Russia and Ukraine has brought international attention to the vital role that Russia and Ukraine play in the global economy as leading producers of agricultural commodities, especially the hub of cereal crops such as wheat, maize, and barley (refer to Figure 2). Glauber et al. (2023) argued that Russia and Ukraine are forces in commodity production and supply across the globe. For instance, between 2019 and 2021, they held a combined market share of 34% in the wheat sector, 26% in the barley sector, 17% in the maize sector, and 75% in

Figure 2. The 2021 destination of Russia and Ukraine maize and wheat exports.

source data: (Glauber et al., 2023).



the sunflower oil sector of the worldwide agricultural trade. This portrait has been spoiled because of the conflict; Ukrainian exports have dropped drastically, while Russian exports have dropped and then recaptured.

Figure 2 shows that whilst global wheat exports grew by an average of 2.3% each year between 2012/13 and 2021/22, those in Russia and Ukraine grew by an average of 10.0% yearly. Maize exports from Russia and Ukraine grew by an average of 7.6% and 6.5% annually, respectively, over the same 10-year period. Therefore, wheat exports have traditionally gone to countries in North Africa and Western Asia due to their proximity to the Black Sea, and around half of the Russian and Ukrainian wheat exports went to those two nations between 2019 and 2021 during COVID-19.

Figure 2 demonstrates that approximately 86,951,701.68 metric tons of grain were exported through the black sea to various locations. Further analysis shows that of the grain tonnage, maize accounted for 32,006,584.66 metric tons, of which 28,319,550.13 metric tons were from Ukraine and 3,687,034.53 metric tons were from Russia. Wheat accounted for the remaining 54,945,117.01 metric tons, of which 19,485,783.64 metric tons were from Ukraine and 35,459,333.37 metric tons were from Russia.

Glauber et al. (2023) suggested that Russia's share of the global wheat export market increased to 13% in 2019–2021, following a 20% increase over the previous two decades. According to Figure 2, Ukraine's wheat exports have increased recently, particularly to emerging markets like Indonesia, the Philippines, and Pakistan. Figure 2 further shows that nearly 40% of all of its wheat sales went to Asian markets in the period between 2019–2021, and additionally, almost 13% of Russian exports and 8% of Ukrainian exports in 2019–2021 went to African countries south of the Sahara, a modest but expanding market.

Glauber et al. (2023) indicated that maize exports from Russia and Ukraine have a different customer base than wheat. Figure 2 shows that nearly a third of both countries' maize exports have gone to Asian markets like China in recent years. North Africa and Western Asia, including Middle Eastern nations like Syria and Turkey, receive the balance of Russia's maize exports. Ukraine also has a strong presence in North Africa and West Asia markets, representing almost 30 % of its 2019–2021 exports. Glauber et al. (2023) argued that Ukraine still exports around 40% of its maize supply, mostly to Europe, where feed producers prefer non-GMO maize and still commands the south of the Sahara, where neither Russia nor Ukraine is the major supplier of maize.

COVID-19's effects have breached the protective barriers of market participants tasked with delivering agricultural extension and consultancy services to farmers to boost productivity and production. Empirical data supports that many farmers, and extension and advisory personnel are among the millions of individuals who have died as a result of COVID-19 (Muthazhagan et al., 2021; Rahman et al., 2021; Strangfeld et al., 2021). Experts have stated that the world's fundamental economic, environmental, and social pillars, such as health and education delivery have crumbled in numerous instances (Cheval et al., 2020). Furthermore, the impact of COVID-19 between 2019 and 2023 highlighted how vulnerable the farming system is to worldwide contagious disease and its health and economic consequences (Global Hunger Index, 2021).

COVID-19 appears to have hindered information and technical exchange, particularly among developing-country rural women and youth farming communities, depriving them of their rights to information, life, and development. According to Alvi et al. (2021), during the COVID-19 lockdown, almost 27% of women had no access to extension or advisory services. Furthermore, women surpassed males in terms of effort maintenance, subjective desire, and exertion ratings for minor rewards, but trailed in invigoration (Lewis et al., 2023). Notably, males exerted more effort than women in exchange for more incentives, allowing them to perform at the same level as women (Lewis et al., 2023).

The World Health Organization's COVID-19-suggested mitigation measures aimed at stopping the virus's transmission, implemented by all countries worldwide, have unfortunately had severe economic, environmental, and social effects on extension and advisory services (Karamidehkordi et al., 2021; Oswake, 2021; Rashidzadeh et al., 2021; World Health Organisation, 2021). For example, social distancing, one of the non-pharmaceutical means of restricting the spread of illness by separating two or more persons at a distance of at least three meters, has diminished agricultural-related meetings where knowledge sharing is vital for many farmers (Hamidi et al., 2020; Nicola et al., 2020). The implementation of strict lockdown measures, such as the closure of agricultural universities and colleges, the prohibition of public meetings, and the requirement of masks, as a means of slowing the spread of the COVID-19 pandemic, has reduced the sharing of agricultural extension information and technologies (Acheme & Vincent, 2021). In certain cases, collected information revealed that these actions were to blame for higher commodity prices, even though farm and manufacturing output had been substantially curtailed.

Most developing countries categorised as import-dependent appear to have suffered from agricultural input and knowledge market inadequacies. For example, since farmers lacked markets to sell their goods and services, it was estimated that most input prices in Zambia and neighbouring countries increased by more than 100%, barring numerous cadres of women and youth from market participation (Adnan & Nordin, 2021; African Development Bank Group, 2021; Oswake, 2021). It reduced agricultural production and productivity among smallholder women farmers, lowering their contribution to the national, environmental, social, and economic sectors (African Development Bank Group, 2021).

On the environmental aspect, the pandemic has had a variety of environmental repercussions. On the one hand, since human activities that contribute to air pollution in many cities declined, lockdowns and restrictions temporarily lowered greenhouse gas emissions. These transiently advantageous effects on the environment have been mentioned in research studies. However, the growing usage of personal protective equipment (PPE), such as gloves and masks, has led to an increase in biological waste and plastic pollution, posing a new environmental concern which increases the cost of agriculture and public health extension services to the countries (Roberts et al., 2022).

According to numerous assessments, COVID-19 increased agricultural input costs in most countries (Ceballos et al., 2020; Peel, 2021; Weersink et al., 2021). The limited supply from Russia and Ukraine has pushed this higher. According to Markets and Markets (2023a), the worldwide feed market will rise due to feed preservatives and is estimated to be worth US$4.8 billion in 2023 and up to US$6.7 billion in 2027, with a compound annual growth rate (CAGR) of 6.7%. Feed preservatives are chemicals or extracts given to feed items to enhance growth and restrict disease onset (Markets and Markets, 2023a). Feed acidifiers, mould inhibitors, antioxidants, and antibacterial agents are examples of feed preservatives. Feed preservatives are manufactured for a wide range of livestock species, including but not limited to cattle, poultry, swine, aquatic species, and even equines and companion animals (Hasimuna et al., 2019; Maulu et al., 2020).

The prevalence of zoonotic infections, which may be transmitted from animals to humans via contaminated food or water, has increased in recent years. Some of the most frequent foodborne pathogens, such as *E. coli* and salmonella, can be stopped in their growth by employing feed preservatives (Crameri et al., 2015). In his research and lectures, economist Raworth (2020) stated that "linear economists", who taught that markets operate linearly, are to blame for agricultural market systems' failure to sustain themselves in the face of repeated historical upheavals. According to Hajer et al. (2015) and Crowley et al. (2021), the world's problems go beyond mere sustainability theory, and as a result, corporations should embrace regenerative development frameworks that account for every action they do. The goal is to engage and broaden public engagement in a bottom-up, fractal-like, multi-scaled, community-led planning process in which stakeholders, notably local farmers, actively develop, construct, and contribute to the future they envisage for their community and business (Crowley et al., 2021).

3.3. COVID-19 and women in agricultural development

Studies have shown the importance of women and gender, extension services, and COVID-19 in the agricultural market system development and growth space (Islamic Development Bank, 2020; Lamontagne-Godwin et al., 2017; Scoones et al., 2019). World Bank records that advantages are multiplied when women have equal access to economic opportunities through sustainable extension service provision. Women who earn money can invest in their children's and families' well-being, contribute to their communities, and help economies thrive (Hartwig, 2021). However, COVID-19 has been reported to have reduced the accessibility, availability, affordability, and sustainability of the traditional agricultural extension and advisory services on the participation of women and youth in the agricultural market system (Cattivelli & Rusciano, 2020; Evans & Carvalho, 2022; Zen et al., 2022).

Studies indicate that women have been excluded from accessing affordable extension services because COVID-19 reduced the economic, environmental, social service, and product factors that held them together (Kiani et al., 2015; Matthew et al., 2020; Zhukovska, 2020). Extension services, also known as intangible goods such as attention, advice, access, experience, and affective labour, though critical in the development of the agricultural sector, have been hampered in terms of flow from the service and product providers to the consumers who are the farmers due to the effects of COVID-19 (Katz et al., 2020; Saucedo-Martínez et al., 2018). Sasakawa African Association (SAA) (2020) and Hansen et al. (2019) argued that the production of extension information has long been regarded as a good public service, driven by information technology to meet various consumer market segments. A public product can only be supplied to all if it is first supplied to one whose availability is unaffected by the usage of one consumer such as roads and public extension services (Kidd et al., 2000).

Research has established that during the COVID-19 disruption of extension service delivery systems, governments were well-placed to absorb the transaction costs involved in making extension services available to farmers (Katz et al., 2020; Saucedo-Martínez et al., 2018). However, most developing countries were caught off guard because their funding was already low, even before the COVID-19 pandemic set on. The costs of determining who is interested in making a transaction and who should be included in the decision-making process, the costs of exchanging information between parties, negotiating to reach a decision, and the costs of uncertainty about the outcome are all included in the decision-making process transaction costs.

However, many economists now regard it as the fourth industrial sector in which COVID-19 appears to thrive. Snapp and Pound (2017) revealed that investing in women's and youth's information technology capacity yielded higher returns when extensions and services were not interrupted all year round. This is especially true in developing countries, where women have been disadvantaged for many years but are highly involved in agricultural development.

ACDI/VOCA, a non-profit organisation, used the Women's Empowerment in Agriculture Index (WEAI) methodology to understand the interrelationship between production, income, resource, and leadership impact on gender and extension service provision. For example, the Feed the Future Ghana Agricultural Development and Value Chain Enhancement II program used a simplified WEAI that consisted of four extension training domains: production, income, resources, and leadership. According to the program, women empowered in four domains: production, income, resources, and leadership, have 62% higher yields than women who are not empowered in any of the four domains. Without COVID-19 disrupting the extension delivery system, women are 27% more likely to use non-saved seeds and 58% more likely to use fertilizers when they have a say in the purchase of agricultural inputs and services, leading to the resultant increased yields of 23% (Agrilinks, 2021; Mphande et al., 2023).

The digital extension delivery systems were useful during and after the post-COVID-19 outbreak. However, extension service providers were challenged with attaining the quality and quantity of extension services that enhanced the productivity and production of smallholder farmers, especially women and youth who were and continue to be excluded from most markets. Agricultural productivity, the measure of the ratio of input to output, was found to be reducing among smallholder farmers, especially those in sub-Saharan African countries, even before the COVID-19 pandemic. However, it was found that COVID-19 compromised the right quality and quantity of extension delivery systems for many youths and women. It is further compounded by the geographical location level of education attained and the age of many smallholder farmers disaggregated by gender.

Ngoma et al. (2021) reported that youth resorted to charcoal buying and trading during COVID-19 because the commodity became more expensive due to the high demand generated by urban dwellers. It was worsened because most staff charged with controlling forests in many developing countries were also in lockdown, and as such, messages on the use of alternative charcoal methods were also not readily available. Extension education provision is interlinked to the agricultural growth sector, which positively interconnects with women and youth involvement and participation in the market space. However, studies postulated that the information delivery gap created by COVID-19 mitigation strategies gave birth to harmful unintended complex vices such as deforestation, low productivity, and food and income insecurity for farmers and women at large (IFAD et al., 2021; Jayne et al., 2016).

Studies by Ahmed (2020) and Rahman et al. (2022) revealed that social distance and quarantine mitigation strategies had a significant and long-lasting effect on extension and advisory service delivery systems on a broad scale. Emotional and psychological trauma dejected farming families, affecting access to and delivery of extension services. Before death, the COVID-19 patients' nursing was on women's shoulders, depriving them of opportunities to attend to improved information sharing. During the lockdown and social distance mitigation strategy, extension and health workers were unavailable to visit their farmers, which exacerbated the situation.

Part of the impact is manifested as unpleasant emotions of isolation, news of losing family members, loneliness, and boredom, which vary depending on the individual's sensitivity and experience, and which are difficult to understand (Ahmed, 2020; Hobbs, 2021; Mahmood et al., 2020). People

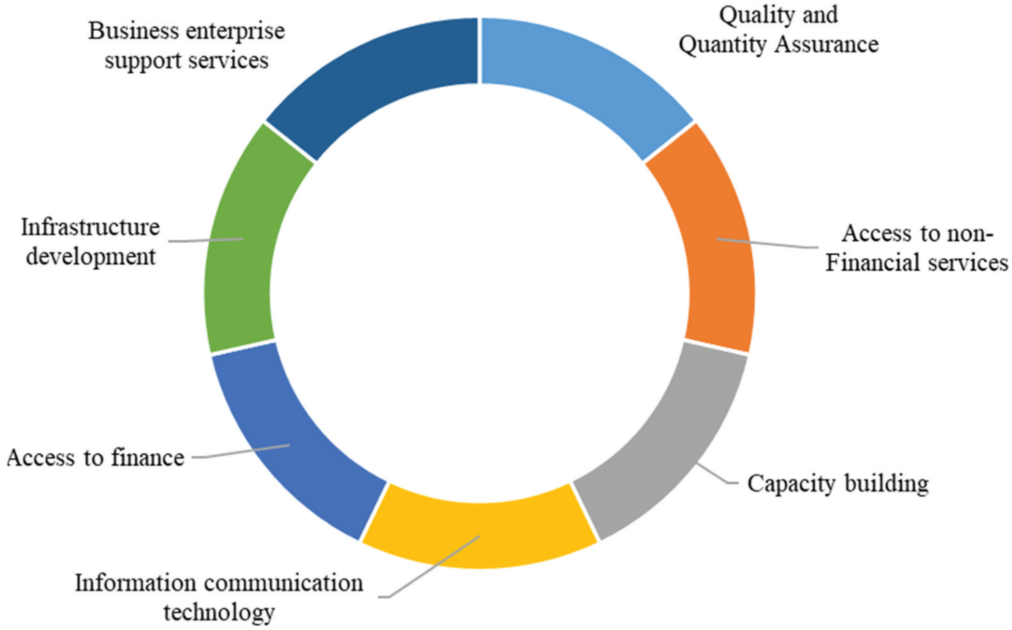


Figure 3. Critical public sector enabling functions for enhancing the business climate environment for women and youth in agriculture during and after COVID-19.

Sources: (Ahmed, 2020; Hobbs, 2021; Mahmood et al., 2020).

had lost hope for life and living, and when a spouse died, the next one would be a wife or another relative who was highly attached to the deceased (Savary et al., 2020). These emotional and related psychological deaths affected the farmers' economic and social standing. The future and the present farming progress became questioned for marginalized individuals and could be attributed to the health and agricultural extension services gap caused by isolation and lockdown. As such, it was discovered that enabling functions to enhance the business climate environment for women and youth in agriculture during and after COVID-19 were critical as shown in Figure 3.

While gender is important in mediating access to agricultural information and extension services, there is a severe lack of gender-responsive extension services, particularly in developing countries. Although women play an important role in agriculture in the region, this is not the case. The inequalities that prevent women from accessing information and the disproportionate economic burden that women face during disasters highlight the urgent need to build resilient and inclusive agricultural extension systems, information, and training (Lubungu & Birner, 2021; Machina & Lubungu, 2019). Due to the current crisis, the disproportionate consequences that women farmers face have been brought to light, and COVID-19 has exacerbated the situation (Ahmed, 2020).

Emerging as a critical object from the impact of the COVID-19 pandemic is the need to boost agricultural productivity while maximizing agricultural profitability. In this climatic condition, agricultural extension services are important in giving timely and correct information to farmers, especially youth and women. It is done to enhance productivity and ensure food security. Disrupted Agriculture Extension Services due to the pandemic and subsequent lockdowns have heightened the demand for accurate and timely information on input and output market access, diseases and pests, insurance, and credit in the wake of the crisis (Saucedo-Martínez et al., 2018).

3.4. Nutrition integration and agriculture extension services

The "nutrition revolution", first recognized as a growing worldwide issue in the mid-1990s, is associated with food and diet security amidst sustainable management. Addressing this during the COVID-19 pandemic required inclusive agricultural extension services. Food and dietary security are critical factors in determining the health of smallholder farmers, especially the aged, youth, and sick, at all levels of the supply chain. Agricultural extension and advisory services offer an ideal entry point for disseminating nutrition information and promoting good nutrition practices among farmers in a culturally acceptable way in the face of COVID-19.

After years of neglect, agricultural extension and consulting services are regaining popularity around the globe. It was echoed in the Second International Conference on Nutrition (ICN2) and its Framework for Action in 2014, emphasizing the importance of developing nutrition skills and capacity to conduct nutrition education activities, particularly for front-line workers, social workers, agricultural extension personnel, teachers, and health professionals. In addition, studies highlight the critical role and potential of agricultural extension and advisory workers in enhancing agriculture intervention nutrition outcomes during and post-COVID-19 (Lee & Moschini, 2022; Munkombwe et al., 2022).

COVID-19 has weighed heavily on the availability, accessibility, affordability, and utilization of the nutritional status of every human on the earth. This is evident in 60% being women involved in the production and consumption of agricultural food production. Over the years before the onset of COVID-19, studies have highlighted the need for an improved extension delivery system that promotes the production, retention, distribution, and consumption of balanced improved dietary at household, national, regional, and continental levels (Leape et al., 2023; Siankwilimba et al., 2022).

A review of challenge factors affecting nutrition in farming communities requiring sustainable extension services included difficulties giving birth, low birth weights, aged faces in children, increased susceptibility to diseases, decreased child school attendance, the development of unhealthy skin, parents' limited access to nutrition education, children's poor temperaments, and a wide-ranging lack of resources to purchase nutritious foods (Siankwilimba et al., 2023). These perceptions were the same regardless of gender, albeit female-headed households tended to be more sensitive to these issues due to most nutrition-related programs' purposeful targeting of them and the age of the household heads (Siankwilimba et al., 2023).

The situation is believed to be triggered by poor extension services coupled with the high poverty levels experienced in rural regions of developing countries, alleged to be over 76%, which contributes to the fundamental causes of the high levels of malnutrition (Chapoto & Subakanya, 2019; Rhoda & Musonda, 2016). In addition, low levels of nutritious crop variety among rural smallholder farmers, according to Mofya-Mukuka and Simoloka (2016), have contributed to high levels of malnutrition among rural households. Most of these households rely solely on their food production systems, and are not informed by reliable extension services, and where crises such as COVID-19 disrupted the food system value chain.

Understanding the fundamental drivers of nutritional and environmental consequences in food production and supply systems, and how they connect and reinforce one another, is essential for improving the distribution and consumption of the required quality and quantity of nutritious foods. However, these drivers were reported to be compromised during the COVID-19 pandemic, triggering most governments to intervene with economic, governance, and environmental policies (Albrecht et al., 2021; Golden et al., 2021).

According to Maulu et al. (2021) and Siankwilimba et al. (2022), connecting agricultural extension and advisory services with participatory learning and action on nutrition and health can enhance a food and agricultural programs' long-term viability and effect on nutrition and household food security. Agricultural extension and advisory workers are arguably the best resources for helping farmers attain nutrition security via nutrition education because of their existing structure/network and broader reach to the community they typically already have confidence. However, the COVID-19 pandemic disrupted the osmotic flow of technical, nutritional extension services, further exacerbated by the supply and distribution of foodstuff to many consumers, of which the majority affected were women. In addition, most families in Southern African countries were affected because their carry-over foods were depleted since COVID-19 appeared during planting season.

Well-trained agricultural and nutritional extension staff are essential to nutritional attainment and food security (Hasimuna et al., 2023). However, due to the rising cost of commodity prices, most smallholder farmers incurred post-harvest losses, with over 40% attributed to COVID-19 effects (Goryńska-Goldmann et al., 2021). In addition, many small and medium enterprises saw their businesses fold, creating gaps in food staff supply and extension services that they pass on to their clients from the manufacturer.

The Global Alliance for Improved Nutrition (GAIN) andHarvest Plus (2021) submitted that agriculture-based extension strategies, such as Nutrient Enriched Crops (NECs), are well-established and have been demonstrated to meet the nutritional needs of smallholder farming families and those who rely on staple foods. The report indicates that these strategies should be included in the food system transformation solutions to benefit smallholder farmers and their families. Extension systems should be able to assure and recommend crop varieties, such as rice, wheat, maize, beans, and other common staples, that have been conventionally bred to contain nutritionally significant levels of iron, zinc, or vitamin A. These varieties contain all the micronutrients essential for maintaining good health, ensuring proper mental and physical development in children, and are helpful in the fight against many diseases, including COVID-19 (Shah Alam et al., 2021).

Similarly, Chinsembu (2021) argues that crises such as COVID-19 call for Africa to invest in extension messages and technologies to preserve and utilise indigenous medicines from indigenous plants to prevent and treat COVID-19. He submits that Africa, endowed with valuable indigenous plants, should take COVID-19 as a new window for novel drugs from indigenous African medicinal plants due to the continent's massive forest endowment potential (Chinsembu, 2021). Furthermore, the indigenous plants are believed to contain natural agents that inhibit the entry of human coronavirus into cells. Chinsembu's (2021) study argues that natural remedies such as turmeric, Eucalyptus essential oil, garlic, cinnamon plant, and Ganoderma fungus are being utilized in areas globally to counteract the effects of COVID-19. In addition, the anti-COVID-19 properties of active plant substances such as glycyrrhizin, clusterin, resveratrol, homoharringtonine, tomentin A-E, sinigrin, silvestrol, and cinnamaldehyde have been proven to offset existing difficulties in the clinical care of the pandemic in the region.

However, Chinsembu (2021) reported that Africa lacks well-packaged marketing strategies to spread the messages about using indigenous medicines. It is therefore noted that traditional medicine has always been a vital source for promoting health in families and communities as demand for its goods and services rises, yet the extension service to promote it is lacking according to Chinsembu (2021). Traditional medicine is well-established throughout most of the world, where it contributes significantly to the culture, health, and wellbeing of numerous groups of which women and the elderly lead in the utilization. According to WHO (2023), for millions of individuals worldwide, it continues to serve as the only source of healthcare, making up a major portion of the economy in several nations' health and agricultural sectors as shown during the COVID-19 outbreak.

Id et al. (2020) and Vijayalakshmi and Barbhai (2021) claim that gender perceptions are profoundly ingrained in human culture, vary widely within and between cultures and evolve through time and generations. Gender, on the other hand, shapes power and resources in all civilizations to the extent that COVID-19 has been recorded to be its disrupter. Variations amongst men and women in their access to productive resources, services, and opportunities such as land, livestock, financial services, and education are one of the causes of underperformance in the agriculture sector, contributing to food and nutrition security, economic growth, and overall development in rural areas (Mphande et al., 2023).

Smallholder farmers are an essential source of food security and nutrition for the poorest people and food production for local and worldwide markets despite the disruption caused by climate change (Maulu et al., 2021) and the COVID-19 pandemic. By evaluating and reacting to the needs of both male and female farmers, Agricultural extension services may help rural communities become more gender-responsive and nutrition-sensitive, and create stronger institutions, projects, and programs in the face of COVID-19 disruption. They may also develop strategies for removing gender barriers in rural homes by distributing gender-appropriate and nutrition-enhancing technology to address nutritional inequity. Several innovative approaches to integrating nutrition and gender within the agricultural extension and advisory services were identified during this study, including the Katori method, sustainable extension model, and multidisciplinary PPP model, even though rural areas face critical challenges such as a lack of trained workforce and food-related myths in the era of COVID-19.

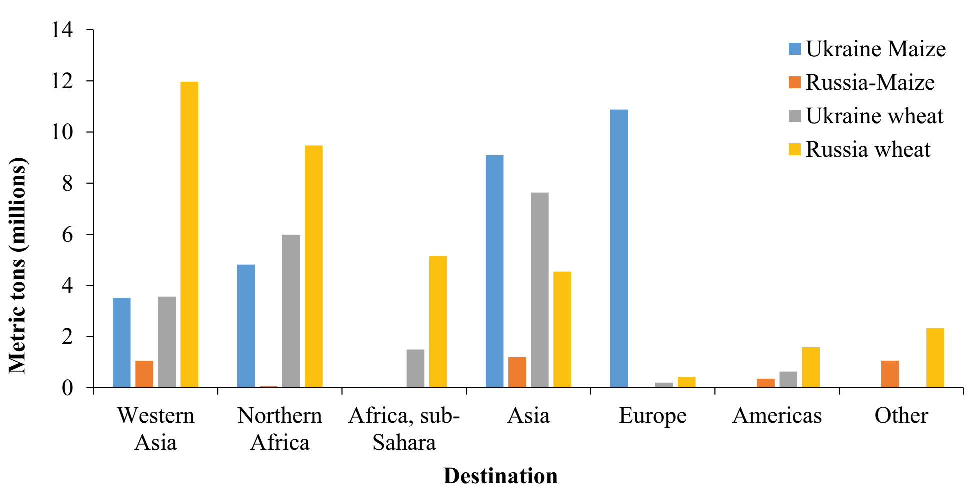
Russia and Ukraine are the major drivers in food production in the world, and their conflict spells a gloomy picture of attaining zero hunger, ending poverty, and achieving sustainable development by 2030 (Glauber et al., 2023). According to Figure 4, Russia, and Ukraine both saw consistent increases in wheat production between 2002/03 and 2021/22, with yields increasing by 1.4% and 1.8% per year, respectively, amid conflict, COVID-19, and climate change. It is noted that even greater increases were seen in maize harvests in these two countries. For example, compared to Russia, where maize yields have increased by 5.5% annually over the past 20 years, those in Ukraine have increased by 4.4% annually. However, research reveals that yields of these crops in Ukraine and Russia have not reached their optimum potential and that cereal output in these countries has demonstrated a high degree of unpredictability over the last two decades, as shown in Figure 4.

Limited access to credit and finance by all farmers, as well as uncertainties in the regulatory framework of the agricultural sector, contribute to the relatively high susceptibility of crop yields to adverse weather conditions and the relatively low yields compared to European Union countries by reducing the use of inputs such as plant and fertilisers and public investments.

What makes Russian and Ukrainian global giants in agricultural production and exports is their high yields per crop per hectare which have grown rapidly during the past two decades, making these countries major players in international markets (Glauber et al., 2023). For example, in 2013, Ukraine and Russia supplied Egypt with over 50% of its wheat imports; by 2021, they supplied Egypt with over 76% of its wheat imports. Furthermore, in 2013, these two countries supplied 8% of Indonesia's wheat imports; by 2021, they supplied nearly 27%. Over the past decade, Ukraine has increased its share of European Union (EU) maize imports from less than 5% to more than 55%. Over the past three years, Ukraine has been a significant provider of China's maize import market, accounting for more than 40% of China's maize imports. China bought more than 80% of its maize from Ukraine during the height of its trade dispute with the United States (Glauber et al., 2023).

Figure 4. Average metric tonnage of harvested crops in Russia and Ukraine per cultivated hectare.

Source: (Glauber et al., 2023).



3.5. Digitalisation in agricultural extension delivery systems

The concerns to transform agricultural extension and advisory systems into gender-inclusive and be sustained have been tabled for several years, even prior to the onset of COVID-19. Communication systems employed in extension delivery systems are a critical determinant of effectiveness and efficiency in transmitting words, messages, ideas, and facts to achieve sustainable poverty reduction among smallholder farmers. However, the gender inequality gap was a significant obstacle despite extension services being transformed into gender-inclusive. According to Bowen and Morris (2019), the most significant barrier to gender equality is the poor adoption of digital extension delivery technology services.

The Internet has revolutionized farming communication systems globally. However, poor digital extension delivery information and technology adoption was reported to cause uneven access to skill-building opportunities, particularly in financial literacy and effective agricultural practices. These were noted around gender disparity in farming and management methods during the COVID-19 pandemic. On the one hand, adopting digital extension delivery systems has proven to be a source of women empowerment through building family and community resilience towards attaining food and income security during the COVID-19 crisis. For example, digital payment and electronic extension services increased women's access to and control over their earnings and business choices. Unlike men, the Bowen and Morris (2019) report indicated that digital extension services helped women reinvest in their families, children, and communities, improving the well-being and long-term viability of various agricultural value chains of their choice.

Lower yields, lower revenues, less nutritious meals, and a reduced capacity to invest in the farm are some of the factors associated with smallholder farmers, especially for women and youth. These challenges are being reduced through the introduction of transformative digital extension services by service providers. World Bank report that businesses increased their usage of digital technology from 31% in the early months of the pandemic to 44% 7–12 months later, while the percentage of enterprises making new investments in digital solutions increased from 17% to 29% (Pangestu, 2021). Women-led micro businesses have been substantially more likely than their male-led counterparts to increase their usage of digital platforms, which is encouraging (Pangestu, 2021).

Compared to previous years, COVID-19 has expanded extension stakeholders' dependence on and use of digital technology to an even greater level than before (Haggag, 2021). Since the COVID-19 pandemic began, digital agricultural technologies have helped smallholder farmers access advice, finance, inputs, and new markets for their goods, though it remains a challenge to most women (Arathoon et al., 2021; Brugger, 2011). The increase in the research and development on the technologies that aid smallholder farmers in participating in the agricultural market system during COVID-19 is supported by different countries (Arathoon et al., 2021; Steinke et al., 2020). In recent years, the breakout of COVID-19 has intensified the digital expansion, which had already begun at the onset of the year but has gained momentum since then.

In the agricultural industry, COVID-19 had the potential to start a digital revolution by providing smallholder farmers, especially women and youth, with the tools and knowledge they need to enhance crop yield. Moreover, for most of the world's population, agriculture is their principal source of income. As a result, digital breakthroughs in agriculture can help the world's poor more swiftly than digital innovations in developing markets, particularly in rural regions.

Millions of extension experts from the public, private, and civil society provided extension and advisory services to farmers worldwide, especially during the COVID-19 pandemic, despite the threats of contracting COVID-19. However, the public sector in developing countries is a significant player in extension and advisory services and has difficulties meeting farmers' needs due to the financial challenges of funding, even when digital development has unlocked some of these challenges. Today's task is to institutionalize new paradigms and alter organizational culture to reward innovation. Moreover, reorienting extension priorities in emergencies and afterwards is required to guarantee timely and quality extension and advisory service systems (Chander & Rathod, 2020).

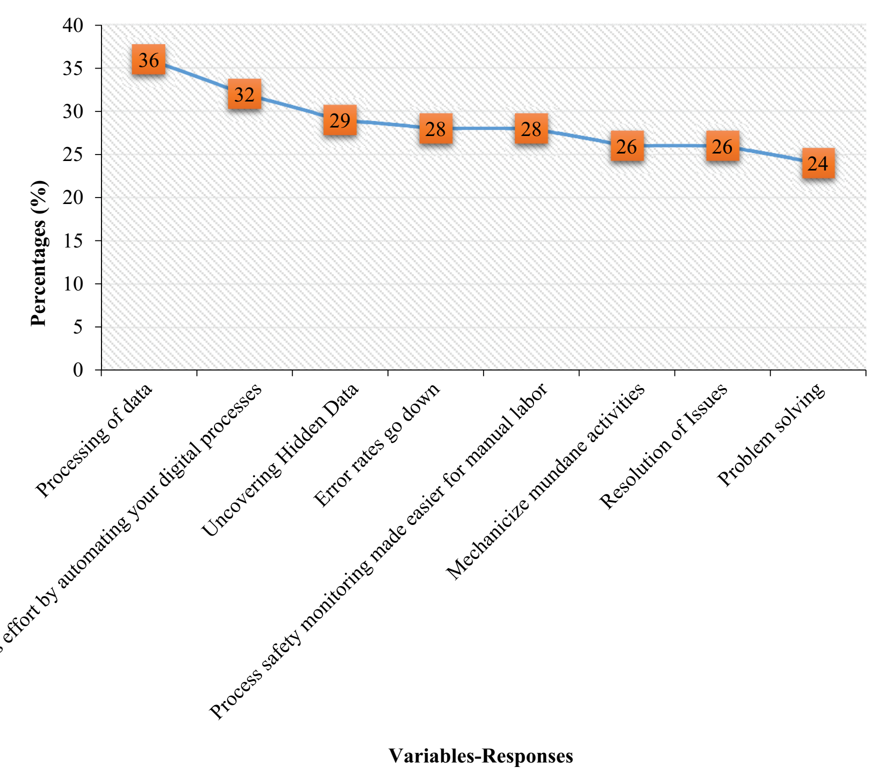
According to the United Nations Statistics, global trends and extrapolations prescribe that people worldwide will increase to 9.8 billion by 2050 and need smart technologies and information to sustain them. Such an upsurge in population growth will impact each countries' growth and food security (Baldos & Hertel, 2014). To ease these difficulties, the fundamental solution will be advanced in agriculture (Ganguly et al., 2017). Haggag (2021) is confident that the calculated introduction of mineral fertilizer and the industrialization of production processes, connectivity, and data management can drive the next revolution in the history of agriculture, specifically smart farming or meticulousness farming.

Consequently, the advancement in farming not only assists family smallholdings but sustainable development as well. Attention given to making the agriculture sector more productive and sustainable will reduce food insecurity and alleviate poverty. However, Pankomera and van Greunen (2019) conducted systematic research to examine how mobile commerce could benefit the informal sector in Africa around the potential obstacles and adoption factors. The research found that embracing e-commerce can result in productive, transformative, and incremental advantages for the user, although there are technological, social, and financial obstacles. The study further stated that these factors were significant in influencing the adoption of mobile commerce in Africa's informal sectors, including technical factors, awareness or knowledge of adopters, perceived usefulness and ease of use, affordability or perceived cost, perceived security and trust, accessibility, access to financial services, social factors, human capital, and asset endowment, regulatory support, and financial inclusion.

A recent survey by Statista (2023) posted that about 70% of workers in America are advocating for using artificial Intelligence (AI) in their professional jobs. Figure 5 shows that most respondents

Figure 5. Percentage of respondents advocating for artificial intelligence or digitalisation.

Source: Statista (2023).



also mentioned several activities they would be happy to forgo fully. Therefore, 36% prioritize data processing; another half would welcome AI assistance. Conversely, privacy and security concerns were identified as the top two reasons for declining AI among survey respondents who did not want to utilize AI at work, as shown in Figure 5. It shows that COVID-19 has influenced the growth of digitalization in many sectors of the economy, not limited to agriculture.

Arathoon et al. (2021) maintains that restrictions on in-person gatherings were moved online with added COVID-19 advisory tools by agritech, multi-national organizations (MNOs), and agribusiness firms. As a result, consumer demand surged, countering losses in the lodging industry and driving much of the farm e-commerce increase. In addition, the demand for inputs grew as farmers battled to get them. As such, government quickly aligned its subsidy programs to digital disbursement and management. Digitizing agricultural subsidy systems, for example, governments have accelerated the adoption of digital financial services. Fees are being waived, and MNOs and governments are increasing transaction limits to encourage mobile money adoption.

A recent study indicated that digitalization has contributed to the global expansion of aquaculture, which has benefited women and youth (Markets and Markets, 2023b). In fish farming, for instance, industrial pumps and components are utilized to transport water from one site to another. Therefore, according to Markets and Markets (2023b), the global market for fish transfer pumps is rising as a result of technological improvements, the presence of major players, and the need for process optimization to serve the needs of a growing population. Numerous contemporary trends, such as automation, Internet of Things (IoT) disruption, product innovation, and the outbreak of the COVID-19 pandemic, are transforming the market and presenting growth potential for market participants, particularly women and youth (Mapiye et al., 2021; Siankwilimba et al., 2022). As a result of globalization and market segmentation, consumer awareness of numerous automation trends that help the poorest in developing nations has increased (Vandome, 2023). The liberalization of international trade markets, manufacturers of agricultural technologies such as industrial pumps are expanding their global presence to service remote markets (Mapiye et al., 2021). Consequently, it appears domestic market participants are expanding their product offerings to gain a competitive edge over international market participants globally.

3.6. Sustainable agricultural extension services provision and enabling support services

The extension system has become increasingly pluralistic over time, relying on various delivery modalities and financing sources, both public and private, for several reasons (Norton & Alwang, 2020). First, the traditional emphasis on technology transfer and farm management information supplied by the public sector has gradually given way to a broader focus on public and private advisory services, addressing marketing, environmental sustainability, pest diagnostics, and risk management over the past four decades. The agricultural extension system has been quietly shifted away from message delivery and toward converting scientific discoveries to make them more accessible to farmers due to the advancement of information and communication technology (ICT) (Rose et al., 2017). Anderson and Feder (2004) suggested that transferring information from the worldwide knowledge base and localized research to farmers is one of the primary aims of the agricultural extension system. However, other objectives are meant to assist farmers in clarifying their objectives and prospects, teach them how to generate better choices and encourage desired agricultural production. Extension services offer human resources as a factor in production-enhancing inputs, such as information flows, that can potentially enhance smallholder farmers' livelihoods.

An enabling environment is needed for all players to offer all-encompassing support for long-term agricultural extension service provisions to improve and sustain food security (Hasimuna et al., 2023). It includes long-term management and control of infectious diseases like COVID-19, proper research and technological development, extension and training, credit, supportive policies, fiscal and legal structures, and infrastructures such as roads, transportation and communication networks, storage, processing facilities, and markets (Jamal et al., 2014; Nakasone & Torero, 2016;

Snapp & Pound, 2017). Governments have established and implemented various agricultural policies, regulating extension services in developing countries (Aderinto et al., 2020; Kebebe, 2019; Sikora et al., 2019; SNAP, 2016). This enabling environment is usually part of a government's agriculture policy, linked to its main national development goals to sustain the agricultural sector. In addition, to promote inclusive development, the agricultural and extension allow private sector players to participate as sector players in product and information service provision.

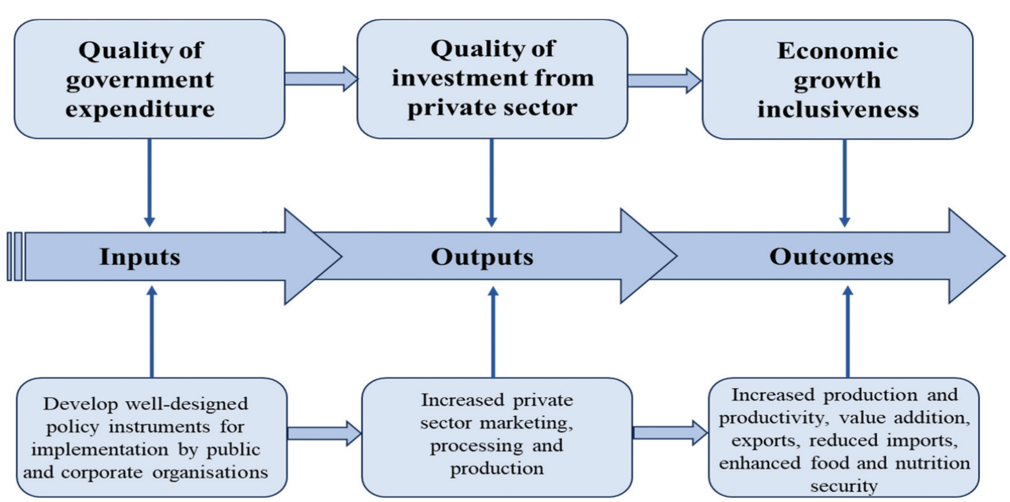
In an organized and functional extension system, civil society, non-governmental organizations, donor initiatives, and the private sector would work alongside the government, providing additional assistance and performing tasks that the government cannot or would not do. Studies have shown that developing countries that underwent market liberalization also liberalized their agricultural sector and extension service provision systems (Chander & Rathod, 2020; Vandome, 2023). However, most developing countries have continued to suffer from inclusive growth and sustainability due to poor policies. In times of economic, social, and environmental shocks (Rizov et al., 2023), Figure 6 illustrates how the agricultural supply system, from input to final consumer of agricultural goods and services, could be developed. These could be accomplished once governments increase their expenditures to encourage the private sector to make quality investments, resulting in inclusive economic growth while using policy feedback as a crucial tool.

The government needs to implement some of the vital factors to enable sustainable private sector participation in the agricultural extension market system are infrastructure, the rule of law, and a stable monetary market (Bruce & Costa, 2019). Infrastructure is critical in unlocking development by incentivizing the private sector to invest in their extension services and products among smallholder farmers. Manggat et al. (2018) describe infrastructure as the organizational framework and physical facilities the community requires to function well. Industries, buildings, roads, bridges, health services, government, and other infrastructures are included in this category. Manggat et al. (2018) claim that infrastructure development is necessary because it impacts the economy's demand and supply patterns, in addition to the buying and selling of goods and services. For example, electricity, water, and improved transportation are essential to rural extension economies' development (Rahman et al., 2021; United Nations Food Systems, 2021).

It should be noted that extension service providers rely on effective public investment and infrastructure management to survive and sustain their agricultural-based businesses. A critical look at the economy shows that infrastructure development may influence the employment rate, productivity, and income and provide additional value to the whole economy (White, 2012).

Figure 6. The agricultural tool that can be used to improve the standard of public spending on agriculture and guarantee accountability in a market that can adjust to shocks in the economy, environment, and society.

Source: authors computation.



Infrastructure development may also help to promote political unity and decrease geographical disparities among societies. Moreover, infrastructure development relates to the supply of essential infrastructure amenities such as road and highway building and the availability of transit, bridges, ports, and telecommunication networks.

Digital infrastructure unlocks the limitations of extension delivery systems which were prominent with traditional extension models (Makalalag et al., 2021). The capacity to conduct business on the Internet is becoming increasingly crucial for the private sectors involved in agricultural and rural development. This technology appears to have come with a bang without leaving anyone behind. It is now a tool to deliver and relay extension information and products by extension market players. Market players involved in extension service provision in rural areas worldwide request improved connections to make service delivery real-time. The United Nations Food Systems (2021) attest that the COVID-19 pandemic precipitated a rapid change in e-commerce, and food markets that already had a well-established digital infrastructure were better positioned to pivot their business models.

Strict rules are necessary to promote market transactions while also ensuring high-quality food. However, they are frequently structured and enforced to increase transaction costs and be excessively expensive for small and medium-sized enterprises (SMEs). As a result, policy changes were the second most often sought type of assistance by SMEs, according to the Siankwilimba et al. (2023) study.

Applying and reinforcing laws should be fair to all market players to ensure transparency in the extension market. Private sector players want to invest where corruption is treated as a deterrent to development. As such, it is a well-known fact that corruption causes delays and increases expenses in many places, notably when obtaining trading licenses and transporting goods and services within the agricultural market system. Inclusive tax regimes favouring all players would promote equal chances of participation in the market (Rosca et al., 2018). Therefore, well-set laws are only as effective as the quality and justice with which they are enforced, regardless of the environment in which they are applied. Food insecurity, which is primarily caused by poor market inclusion for women and youth poses a serious threat to the goals of ending poverty and hunger, necessitating the strategic formulation of policies across various domains associated with sustainable agricultural delivery systems globally (Rizov et al., 2023).

4. Conclusions and future prospects

COVID-19 affected the agricultural extension system by limiting information access and increasing costs due to lockdowns. Digitalization holds promise but varies in adoption. Multisector coordination is crucial during crises. Agricultural extension should prioritize gender and nutrition sensitivity. Agriculture, notably in developing countries, remains the least impacted sector. The private sector's involvement in the extension system is vital, with public-private partnerships proving effective. The complexity of COVID-19 affected various sectors, including private and public, extension staff, donors, funding, and research systems, impacting nutrition. Technological advancements and land expansion seek to enhance agricultural output but face challenges like insufficient research investment, rural infrastructure deficits, and water scarcity. Direct funding to the health sector can alleviate extension system challenges, with specific funding offering quicker results. Extension services play a critical role in nutrition. Traditional models proved inadequate during COVID-19, emphasizing the need for research on servant and innovative leadership in crisis response. The impact of early warning systems on the extension system and smallholder farmers remains uncertain. Future research should investigate how COVID-19 has reshaped extension models for a holistic agriculture and extension delivery system.

Author contributions
ES generated the idea, defined the objectives, and critically reviewed the manuscript. MEH and JHM assisted in defining the objectives, coordinated the writing of the manuscript, and participated in the writing and reviewing of the manuscript. BHM, CM, VM, MC, LPLC, AF and GP critically reviewed and made substantial contributions to the manuscript. OJH, SM, JM and MBM participated in writing the manuscript.
All the authors read and approved the final manuscript.

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