Harnessing the Digital Technologies to Strengthen Resilience of African Food Systems during the COVID-19 Pandemic and Beyond

Lavhelesani Rodney Managa
Africa Institute of South Africa, Human Sciences Research Council, South Africa

Abstract

Because of its direct and indirect impacts on food production and value chains, COVID-19 pandemic severely affected smallholder farmers, who are responsible for feeding most of the population in vulnerable communities. The lockdown and movement restrictions constrain the farmers from accessing distant and often profitable markets in many countries. In some countries, COVID-19-related interruptions affected labour availability, on-farm commodity inspection and primary production operations (land preparation, planting, harvesting etc.), delivery of farm inputs, mechanisation, essential agricultural extension services. However, farmers in developed countries took advantage of digital technologies at their disposal to adapt to the impacts of COVID-19 on agricultural production, labour availability, input supply and marketing. For instance, digital agriculture solutions that link farmers to buyers and logistics services helped to lessen the effects of restricted market access and aggregators. Most of the smallholder farmers in Africa have not benefited from this opportunity, as they lack basic digitalisation infrastructure and capacities. Therefore, increasing investment in technologies to help smallholder farmers could yield far-reaching benefits and prevent major disruptions on the food value chain during pandemics. Hence, public policy should put more emphasis on boosting digitalisation complementary infrastructure and human capacity, address gender access to technology disparities, and minimise risks associated with digitalisation.

Introduction

Food systems are vulnerable to multiple environmental shocks and sudden socio-economic changes, which in turn affect the status of food insecurity. Food systems are impacted by social and ecological systems, which are formed of complex interacting biophysical and social

factors.[1,2] At a basic level, the food system is comprised of food production, processing, distribution, retail, and consumption.[3] Given the interconnectedness or linkages between these activities, the disruption in one chain could negatively affect the entire food system and its ability to feed the population. The vulnerability and resilience of food systems vary across countries and regions. In sub-Saharan Africa, the food systems of many countries are already highly vulnerable to multiple shocks, including sudden policy changes in the system. The food systems in the region still lack a fundamental resilience mechanism including improved food production, processing, packaging and road and rail networks. This was evident at the beginning of current COVID-19 pandemic.

Despite the region only having confirmed a small proportion of COVID-19 positive cases compared to other regions, sub-Saharan African livelihoods have been severely affected by this pandemic.[4,5] This is caused by over-dependence on food imports, lack of capacity and poor agricultural productivity.[6] For instance, 'Africa food imports between 2016 and 2018 accounted for 86 per cent of its food increasing an annual food import bill to about $135 billion and estimated to exceed $100 billion by 2025'.[7] This indicates over-reliance on the global food value chain and can be detrimental to local food security, especially at a time of national and regional disasters. Any trade disruption could lead to serious consequences for food supply and accessibility within the region. COVID-19 pandemic through its direct and indirect effects on agricultural production and value chains exposed major weaknesses in African food systems. At the start of the COVID-19 pandemic, several countries experienced disruptions in the food value chain, which exacerbated high food prices. The pandemic further forced import-export restriction policies, restricting the global trade in food commodities and agricultural inputs.

The impact of COVID-19 pandemic experienced by many countries suggest the need for strengthening the resilience of current food systems to cope with future pandemics and other existing shocks. While the world markets are showing steady recovery, the disruptions of African food value chains by the pandemic are likely to take longer to recover. This experience, therefore, underlines the importance of addressing the long-term resilience needs of smallholder farmers in Africa who provide food to the urban and rural population.

In recent times, there has been some improvement towards the resilience building of smallholder farmers to adequately respond to environmental shocks and the effects of socio-economic changes. These include price drops, pests and disease management, humanitarian support, nutrition, and climate-smart agriculture. However, COVID-19 has proved that such interventions and efforts need to be redoubled to improve the resilience and sustainability of food systems.

Despite its immense impact on the food value chain, the COVID-19 pandemic also opened a number of avenues that can be exploited to strengthen the resilience and competitiveness of food systems in developing regions. The main question is how can African agricultural systems better adapt to economy-wide impacts of pandemic disruptions? As we have seen across many sectors, the pandemic revealed the role of digital technologies in enabling success under unfavourable conditions. In the agricultural sector, digital technologies also offer the possibility of an alternative equilibrium, one where smallholder and emerging farmers better adapt their production systems to a changing environment. Modern agricultural technologies could

provide a variety of innovative solutions to manage and overcome the impacts of COVID-19 on agricultural production, labour availability, input supply, and marketing. For example, drone-farming and digital extension applications can assist farmers to adopt labour and input saving technologies and reduce human contact, while digital marketing tools that link farmers to markets, logistics and distributions reduce the impacts of restricted market access and aggregators occasioned by COVID-19 control measures.

To this end, this article draws on lessons learnt during the current COVID-19 pandemic to highlight critical opportunities offered by digital technologies for improved food-chain systems, particularly for smallholder farmers with limited capacity to play a role in the global markets. The paper outlines how digital technologies can prevent major disruptions to the food value chain of vulnerable societies. It further highlights the feasibility and possible mechanisms for a wider digital application in agricultural production systems, marketing, and value chains.

Methodology

The study applied a desktop-based research method to collect the data. To retrieve the information on the subject under investigation, search engines such as SA ePublications, Google Search, Science Direct, Google Scholar, Ebschohost and SpringerLink were utilised. A literature search was performed using the following key terms: ['COVID-19' or 'corona virus'] and ['food systems' or food value chain'] and ['digital technologies'], with and without the term 'Africa' and 'sub-Saharan Africa'. In this way, the papers and reports referring to COVID-19 but not linked to the food chain were filtered out. Secondary data from published resources was analysed and synthesised according to pre-determined sub-themes that enabled broader meaning and understanding of the narrow context from the literature consulted. Even though COVID-19 disrupted entire food value chains, this paper focused mostly on the food systems of smallholder farmers and rural communities that depend on these systems for food supplies. As there was a limited number of peer-reviewed papers on this topic, COVID-19 rapid assessments reports, and other local and international institutional reports were the dominant sources of information.

While the publications of studies conducted outside Africa were broadly consulted, the data obtained from studies investigating African food systems were prioritised. Statistics that are reported in the paper were supported by citations of primary sources from which the data was extracted. Therefore, the results from the studies whose methodology could not be clearly understood were consequently not synthesised for evidence purposes, and therefore excluded.

Results and Discussions

Vulnerability of farming systems and its implication to food security

Over the years, the resilience of farming system has been tested which has serious implications for national and household food security.[8] The productivity of smallholder farmers remains very low due to factors including the impact of climate change, poor access to agricultural

inputs, credit and markets, post-harvest losses as well as ineffective policy frameworks. Yet, these smallholder farmers contribute to food availability and access for both rural and urban populations. In developing regions such as sub-Saharan Africa and Latin America, 'smallholder farms produce more than 70% of the food calories and are playing a key role in maintaining nutritional diversity.'[9]

The outbreak of the COVID-19 pandemic impacted global food security in different ways. In most instances, the virus control measures such as lockdowns and social distance requirements caused major disruptions in food value chains. These disruptions have affected the ability of billions of people around the world to access enough food and nutrition.[10] It is suggested that 'the hunger and malnutrition associated with COVID-19 pandemic may have impacted the lives of many more people than the disease itself, especially in regions with weak social safety nets'.[11]

In regions that are most vulnerable to food insecurity, such as sub-Saharan Africa, building a resilient food system is no longer a choice for the survival of citizens. While the need for transforming food system is justified, there are still different views amongst experts on how to reposition the agricultural development pathways in ways that effectively address poor food value chains, hunger and inequality while taking environmental sustainability into consideration. Unlike past shocks, the impact of COVID-19 on food systems cut across the whole value chain and perhaps this lesson could have opened new pathways to foster transformation and build a resilient food system. This includes the urgency of having proactive measures by all key role players, to protect the stability of food value chains at both national and local levels.

Impacts of COVID-19 pandemic on African agriculture and food value chain

In the multi-country rapid assessments,[12] 'about 45% of the farmers interviewed reported that they were unable to hire labour services for their farming activities, while 48% said that the cost of hiring day or casual labour had gone up during the COVID-19 crisis'. In several countries, the virus struck during the main growing season and that had considerable consequences on food production and value chain systems.

Although the evidence is still sketchy, early assessments showed that the pandemic had significantly affected the agricultural value chain, with different countries being affected in different ways (Table 8.1). The ban on public transport and social gatherings, for example, reduced farmers' access to agriculture inputs (e.g. seed, agrochemicals and fertiliser), financial services, farm labour availability as well as output markets. Additionally, the pandemic disrupted the provision of agricultural extension services, leaving farmers with limited ability to manage pests and diseases and improve their productivity. In West Africa, 'COVID-19 mediated disruptions affected labour availability, and on-farm production activities, leading to decreases in areas under rice production, productivity and profitability.'[13] This is not the first time in West Africa where rice production has been disrupted by disease. The Ebola epidemic in 2014 reduced the area under rice cultivation by 3.7 per cent in Guinea, 8 per cent in Sierra Leone and 11.6 per cent in Liberia,[14] leading to a 10 per cent decrease in gross rice production.[15]

The marketing of agricultural produce was also affected by the COVID-19 pandemic. The lockdown restrictions made it difficult for farmers to access distant and often lucrative markets in many countries across the continent.[16] These effects were mostly felt by smallholder and

emerging farmers, as their strategic markets (especially in the hospitality industry) were shut down due to lockdown restrictions (Table 8.1). In Nigeria, it was widely reported that the farmers were returned at police roadblocks with trucks of food commodities while on their way to the market. In a rapid assessment of Zimbabwe,[17] 'about 81% of interviewed farmers reported a significant drop in sales through district and regional markets'. The situation was further worsened by the rising cost of transportation, which added a burden to the livelihood of smallholder farmers. The lockdown restrictions also severely affected the ability of buyers and brokers to visit communities and purchase produce directly from farmers[18] As a result, farmers reported a significant drop in farmgate sales for agricultural produce. In Southern and Western Africa, 'closures of restaurants, school feeding schemes and other local informal food outlets decimated the local market for agricultural produce, especially horticulture, poultry, and dairy products'.[19] The marketing of farm produce by smallholder farmers was further impacted by reduced households' purchasing power due to job loss and reduced income (Table 8.1).

Table 8.1: Synthesis of the direct and indirect impacts of COVID-19 on agriculture and food value chains in selected African countries

Disrupted activities	Ethiopia	Malawi	Kenya	Ghana	Tanzania	Mali	Rwanda	Uganda	Senegal	South Africa	Togo	Zambia	Zimbabwe	Benin	Burkina Faso	Cote d'Ivoire	Mozambique	Niger	Nigeria	South Sudan
Supply and access of farming inputs																				
Disruption in input imports from other countries		√		√	√												√			
Disruption in domestic input deliveries			√	√					√											
Disruption of seeds multiplication at farm level															√				√	
Reduction of input demand																	√			
Agricultural production and harvesting practices																				
Labour shortages for cultivation activities				√				√			√							√		
Labour shortages for harvesting and sorting in the field	√	√		√			√					√	√							

Disrupted activities	Ethiopia	Malawi	Kenya	Ghana	Tanzania	Mali	Rwanda	Uganda	Senegal	South Africa	Togo	Zambia	Zimbabwe	Benin	Burkina Faso	Cote d'Ivoire	Mozambique	Niger	Nigeria	South Sudan
Interruptions of agricultural extension activities			√					√					√							√
Panic harvesting and marketing of pre-mature produce		√										√								
Post-harvest handling and trading of fresh produce																				
Closure of sectors who are strategic target market	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Closure of open access or informal trade markets			√							√			√		√				√	√
Lack of adequate storage		√			√															
Export bans		√										√								
Border closure and delays at port of entry	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Food processing and manufacturing activities																				
Difficulty accessing raw materials							√	√				√	√							
Labour shortages	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Difficulty importing processing technology (equipment, spares)							√	√									√			
Wholesale, retail, and distribution																				
Disruption in accessing food supplies	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Reduced market demand	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	
Increased price of staple food										√										√

Disrupted activities	Ethiopia	Malawi	Kenya	Ghana	Tanzania	Mali	Rwanda	Uganda	Senegal	South Africa	Togo	Zambia	Zimbabwe	Benin	Burkina Faso	Cote d'Ivoire	Mozambique	Niger	Nigeria	South Sudan
Consumptions and utilisation																				
Decrease in consumer buying power	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Limited access to open food markets			√					√					√		√				√	
Shortage of cheap nutritious food	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Panic buying				√		√		√									√			
Change in dietary habits	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	

Source: *Author's synthesis of rapid assessment reports (i.e. APRA COVID-19 Rapid Assessment survey;[20] FAO, WFP, IFAD Assessment survey;[21] FAO-GIEWS FPMA;[22] HSRC, DALRRD, FAO[23])*

In Zimbabwe and Ghana, the COVID-19 pandemic first struck at a time toward 2020 harvesting season and thus disrupted the harvesting and selling of farm produce.[24,25] As a result, losses in production were incurred due to delays in harvesting and post-harvest losses because of extended storage periods as the farm markets get disrupted (Table 8.1). Table 8.1 shows that the disruptions on the agricultural value chain were severe for those countries which imposed a high level of restrictions and countrywide lockdowns. However, Ethiopia, Malawi and Tanzania had a low level of restrictions and the APRA COVID-19 Rapid Assessment survey[26] showed that there were no significant changes in participation in farming activities. On the other hand, Ghana, Nigeria, Kenya and Zimbabwe were among countries that imposed severe restrictions and experienced a significant decrease in farming activities.[27]

However, the extent of COVID-19 effects on the agricultural value chain also depended on the policy response and other support mechanisms put in place by different countries. For instance, South Africa had nationwide lockdown restrictions, but the agricultural sector was declared an essential service allowing most farm activities to continue uninterrupted. This was followed by the government COVID-19 Agricultural Disaster Support Fund which assisted a number of smallholder and communal farmers to acquire inputs to complete the production cycle. For the smallholder and emerging farmers, the access to farm inputs and output markets for fresh produce was severely affected as the informal traders, restaurants and school feeding schemes were shut down during Level 5 national lockdown.

Some countries in the region also initiated national policy responses to limit the impact of COVID-19 on food systems. These responses were varied from the removal of value-added taxes on food products to export restrictions on key food items. In Kenya, the value-added tax was reduced on all goods from 16 per cent to 14 per cent whereas Sudan introduced a ban on sorghum

exports to ensure domestic availability.[28] In order to avoid shortage in staple foodstuffs, Mali banned exports and re-exports of rice, millet, sugar, milk and pasta and reduced customs duties on the imports of rice and milk.[29] This was followed by the introduction of price ceilings on key staple foods, including rice, sugar, vegetable oil and bread. However, enforcement of most of these responses proved to be insufficient due to limited capacities and resource constraints. Most farmers in Ghana and Kenya reported that they did not receive desired relief support during the pandemic which left them destitute.[30]

In response to restricted market access, and weakened value-chain linkages, some commercial and smallholder farmers took advantage of digital technologies at their disposal and quickly went online for marketing of their produce. However, not all the smallholder farmers benefited from this opportunity, as they lack basic digitalisation infrastructure and capacities.

Role of digital technologies to improve resilience of food systems

A resilient food system has the ability to provide food security and sustainable livelihoods even in times of crisis. Although there are a number of limitations, digital technologies played an important role in improving access to produce markets through several online platforms. Unlike the prior Green Revolution that originated with on-farm innovations before spreading to the rural farmers, digital innovations of today are promoting efficiencies at multiple levels along the food value chain. Some of the opportunities presented by digital technologies enabled farmers to improve their household income, livelihoods and welfare.

Promoting inclusive and integrated market access through digital technologies

One of the major challenges among smallholder agriculture has been the failure to integrate them into markets, both global and domestic. This has also limited their inclusion in the development process. In most countries, the majority of farmers sell to and buy from local markets. However, there are market failures and externalities, with high transaction costs for smallholder farmers. Moreover, the markets structures and operating models for these smallholder farmers are very vulnerable to disruptions during times of crisis or shocks. For stance, interruptions in the agricultural supply chain limited the food systems to feed its population during the COVID-19 pandemic. However, this also provided opportunities by offering pathways for multiple innovative responses to strengthen food systems toward sustainability and resilience.

Although the conditions of smallholder farmers in Africa worsened due to COVID-19, some farmers in developed countries prospered during the pandemic by adopting online marketing through digital transformation.[31] Digital platforms became essential during COVID-19 lockdowns as numerous food providers and retailers quickly shifted to online platforms such as the Open Food Network. For instance, estimates suggest that in the People's Republic of China, 'the share of the online market increased from 11 to 38 per cent of total food retail purchases in February 2020'.[32]

At the farm level, digital technology applications help to address market failures and facilitate the integration of farmers in the value chains by enhancing access to information and reducing transaction costs.[33] In 2020, the impact of the COVID-19 pandemic revealed the potential of digital technologies to improve the functioning of neglected food markets. Modern food value

chains introduce additional costs that are often related to information about consumer preferences, especially on quality and food safety. Therefore, digital technologies can help reduce these costs and promote access to markets, addressing many of the constraints smallholder farmers face to become part of the formal economy and global value chains.[34] For example, search costs are significantly reduced in digital marketing compared with the physical, analogue world, and this improves the time efficiency and outcome of searches. As a result, lower search costs can significantly improve the match between buyers and sellers, such as in the context of a digital e-commerce platform and can reduce bargaining costs while potentially adding to the bargaining power of the farmer.[35] Proper adoption of digital technologies showed that improvements in information and communications technology could effectively link farmers to traders and consumers across regions and countries and improve their livelihoods and welfare.

In some African countries, digitisation for smallholder farmers has improved access to services and enhanced smallholders' market inclusion.[36] Inclusiveness typically refers to the integration of smallholders into markets, where activities benefit the local agribusiness while improving the livelihoods of poor communities.[37] For example, digital solutions such as M-Pesa (a mobile phone-based transfer, payment and micro-financing service) and Cargill's Farm Force have been transforming the smallholder farming system in Kenya.[38] However, despite smallholder digitisation benefits, digital technologies need to be carefully implemented as they can be disruptive, modifying or displacing value chain activities and products. Particularly for communities with high inequality, the digital revolution could further disadvantage the marginal farmers who may be left behind in the adoption of these technologies. Therefore, regulating the disruptive effect of digital technologies is essential to ensure sustainable integration of digitalisation in the agricultural and food markets.

Promotion of advisory and extension services during lockdown and travel restriction

Advisory and extension services are important for farmers. It enables them to assess information to make informed decisions on farm practices and production. As shown in Table 8.1, access to advisory or extension service was severely affected in a number of countries including Kenya, Uganda and Zimbabwe. As one of the precautions to reduce the spread of the coronavirus, agricultural extension officers did not engage farmers in groups but visited some of them one-on-one instead or avoided the visit entirely. Therefore, digitising agricultural extension, where farmers use digital technologies to access useful information could provide a sustainable solution during the time of pandemics. Although access to digital technology and the rate of its adoption differ greatly across the regions and countries (the so-called digital divide), COVID-19 seems to have triggered the interest of many smallholder farmers in the opportunities of digital technology.

Promotion of smart and precision farming to recover from the impact of the pandemic and to meet increasing food demand

In some countries such as Ghana, Niger, Togo and Uganda, farmers reported the shortage of labour for agricultural production due to the impact of the COVID-19 crisis.[39] The availability of farmworkers was affected which also increased labour costs. With digital technologies in

place, agricultural productivity could be maximised at a relatively low cost. Digital technologies such as sensors, satellites, robots and drones have shown the potential of transforming farming and agricultural value chains. Sensors and satellites provide early warning information on soil conditions, weather and temperature, or crop growth. They, therefore, enable farmers to achieve better yields by optimising farm management activities. The Internet of Things (IoT) that connects robots, drones and vehicles to the internet can make labour-intensive tasks, such as monitoring plant health or sowing crops more cost-effective and can improve farmer profitability. These technologies could reduce the human interface and ensure an uninterrupted farmer supply chain in times of restricted movement due to crisis. If its implications for human labour are well controlled, digital solutions are a safer approach to strengthen the resilience of the agricultural supply chain and keep the smallholder farmer operational during the time of pandemics and other crises. As already been established by innovation-driven solutions in central and northern Europe, North America, Argentina, and Australia,[40] digital agriculture could drive economies of scale and higher returns on investment for smallholder farmers.

Ensuring inclusiveness, mitigating the risks, and optimising the opportunities of digital agriculture post COVID-19

There is no doubt that digital solutions can increase the efficiency, traceability and transparency in agricultural markets and value chains. However, despite the progressive hype, digital technology adoption in the value chain of smallholder farmers has been slow.[41] In most developing countries, smallholder farmers are still wedded to traditional farming methods, cash transactions, and manual product sales to buyers. With COVID-19 having made the world depend more on digital technology than ever before, it is a time to ensure that the revolution does not leave the marginal smallholder farmers further behind. 'Adoption challenges include the implementation cost, low awareness of benefits, mistrust, and technical difficulties'.[42] These challenges create an environment where a 'digital divide exists between countries, between urban and rural areas, and between men and women. On average, in rural Africa, only 10 per cent of households have access to the internet',[43] making it difficult for digital technologies to be widely adopted. There is also gender imbalances in this discourse, as rural women still have the least access to the internet compared to men. A survey from 33 African countries, indicates that only 24 per cent of rural women have access to the internet via mobile phones, as compared to 32 per cent of men.[44] Due to differences in mobility and access to income, women in rural communities are still limited in their access to and use of ICTs.[45] To ensure equal representation in the digital innovation by smallholder farmers, there should be a good partnership between the public and private sectors, and policy coherence to improve digital infrastructure and skills in rural areas.

In addition, the long-run transformative impact of digital technologies in farming sector, as well as the related risks, have not been fully analysed. For instance, issues related to the ownership and use of data collected through digital technologies on-farm have raised huge concerns. Addressing these issues can further promote digital technology adoption on a wider scale. Other technologies could significantly affect the contribution of labour, capital and other inputs to the production, processing and marketing of agricultural produce'.[46] Thus, the adoption of digital

technologies can result in changes in relative prices, disrupting markets and the welfare of those smallholder farmers who are failing to participate in the digital platform. In low-income countries, connectivity gaps remain between urban and rural areas, posing a challenge to farmers' ability to adopt new technologies, innovate and participate in the digital markets.

Given that the smallholder farmers operate in a complex system, the potential of technology to impact their agricultural value chain needs to be systematically investigated. The issues mentioned earlier point to the necessity for:

> enhanced collaboration between all stakeholders, including governments, the private sector and the farmers themselves, to improve governance mechanisms. This will promote best practices that can shape a regulatory framework that will maximise the benefits of digital technology in the food systems and minimise the associated risks.

However, it is important to note that 'increased technology availability to meet transparency demand does not automatically improve farmer technology transfer and adoption' There are fundamental limitations to technology uptake which need to be taken into consideration, such as 'low literacy rates, and poor mobile and logistics networks in rural areas linking farmers to markets'.[47] Also, farmers' willingness to adopt new technology is greatly dependent on their culture and social norms,[48] coupled with behavioural aspects of innovation adoption such as time preferences.[49]

Lastly, the role of governments in providing an enabling policy environment for adopting innovations and further technological development is crucial. Inclusive development remains key to ensuring that rural smallholder farmers are able to benefit from the digital revolution in sub-Saharan African countries. Improving physical infrastructure is not enough to enable smallholder farmers to engage in digital farming but ensuring access to education is key to the development of rural smallholder farmers.

Conclusion

African food systems were already constrained prior to the COVID-19 outbreak because of a series of droughts, trade barriers, biosecurity issues, rising input costs, deteriorating markets, logistics, processing and research infrastructure. Therefore, the areas for improvement became critical during COVID-19 crisis. A focus on these areas is crucial to strengthen the resilience of African food systems and improve smallholders' livelihoods and welfare. Most of the challenges faced by the farmers during the COVID-19 were identified over the past years, but not enough mechanisms were put in place to efficiently address them. Hence COVID-19 presents a new opportunity to reinvigorate the interest and improved mechanism to build the resilience of the African food system for future crises. Digital inclusion in the agricultural production and food markets can increase productivity and boost resilience of smallholder food systems. However, for digital solutions to transform agricultural sector, more effort should be put into

boosting complementary infrastructure and developing human capacity as well as addressing the gendered access to technology disparities.

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