



Review

The Contribution of Cereal Grains to Food Security and Sustainability in Africa: Potential Application of UAV in Ghana, Nigeria, Uganda, and Namibia

Dele Raheem ^{1,2,3,*} , Moammar Dayoub ⁴ , Rhoda Birech ⁵ and Alice Nakiyemba ⁶

¹ Northern Institute of Environmental and Minority Law, Arctic Centre of the University of Lapland, 96101 Rovaniemi, Finland

² Smart Agriculture Research and Application Team, Ton Duc Thang University, Ho Chi Minh City 729000, Vietnam

³ Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City 729000, Vietnam

⁴ Department of Future Technologies, University of Turku (UTU), 20500 Turku, Finland; modayo@utu.fi

⁵ Faculty of Agriculture and Natural Resources, University of Namibia, 13301 Windhoek, Namibia; rbirech@unam.na

⁶ Department of Natural Resource Economics, Faculty of Natural Resources and Environmental Sciences, Busitema University, P.O. Box 236, Tororo, Uganda; alicenakiyemba@gmail.com

* Correspondence: braheem@ulapland.fi or dele.raheem@tdtu.edu.vn

Abstract: Africa is a net importer of food, especially cereal grains, despite the importance of agriculture in the continent. The agricultural growth in Africa has been undermined by low investment in agriculture, poor infrastructure, high population growth rate, and low adoption of technologies. The agri-food value chain in many African countries will benefit from the adoption of appropriate technologies that are available in the digital landscape to leverage the agricultural sector, make it more attractive to the teeming youth population, and to reverse rural-urban migration. Attention to indigenous cereal grains and other crops that are grown locally and processed into different local foods would ensure food security. However, the availability of these crops in the market is often reduced due to damage before harvest by pests and predators leading to economic losses for farmers. In this article, we review the literature from a multidisciplinary perspective on the relevance of African indigenous food grains to food security in general and we highlight the potential application of drones to increase the yield of cereal grains in three regions of the continent—eastern, western, and southern Africa.

Keywords: food security; food sovereignty; precision agriculture; cereal grains; Ghana; Nigeria; Uganda; Namibia; Africa



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1. Introduction

The importance of food and nutrition cannot be overemphasized, as reflected in the United Nations 2030 Agenda for Sustainable Development through its 17 Sustainable Development Goals (SDGs), especially Goal 2 that seeks to “end hunger, achieve food security and improved nutrition, and promote sustainable agriculture”. There are numerous diverse, healthy, nutrient-dense indigenous and traditional African foods that are losing their place in today’s diet due to lack of scientific understanding and value addition which threaten interest, patronage, and use of such foods to sustainably meet consumer needs of African and non-African markets. The Comprehensive Africa Agriculture Development Program (CAADP) formulated by the African Union has a strong component on sustainability with emphasis in diet diversity as a critical outcome [1]. In order to achieve this outcome, there is a need to focus on the contribution of native cereal grains. The native cereals with the highest potential to secure food security for millions of the African people are African rice, finger millet, fonio (acha), pearl millet, sorghum, and teff [2]. Therefore,

there is an urgent need in Africa to move from an agricultural economy that is dependent on cash crops for export, and dependent on imports and food aid, by encouraging the less known indigenous food crops that have helped to maintain food security in the past. Even though these traditional foods and related local know-how have been critical for the survival of society in the past, they remain less explored, less popularized, and less shared, both within the continent and beyond. In the last few decades, there have been efforts to bring a limited number of African traditional foods crops such as teff into the global market because of their economic, nutritional, and health values. Nevertheless, a lot remains to be done in identifying the different attributes of these traditional African foods. Due to their adaptation to prevailing climate in the continents, increased utilization of these African indigenous crops is paramount in building climate-resilient food systems for food and nutritional security in Africa. A broad understanding of ways of eliminating obstacles in the traditional food systems is key to their development. This review is an attempt to use precision agriculture in controlling pests in African cereals. It explores the option of improving the productivity of cereals in three regions of Africa (east, west, and south), they represent sub-Saharan Africa precisely—Ghana, Nigeria, Uganda, and Namibia using information and communication technology (ICT) with focus on African indigenous cereal grains. The four countries were selected since the authors are familiar with their agricultural practices having lived and conducted research in these countries. The ICT tool in this case is drone technology to control the *Quelea* birds that have historically ravaged the small-grained cereals, particularly pearl millet, barley, finger millet, proso millet, oat, rice, teff, sorghum, and wheat. ICT will accelerate the desired goals envisioned by the SDG 2030 and the African Union Agenda 2063. In the next section, we highlight the potential application of unmanned aerial vehicles (UAV), with focus on how food security is enhanced through the use of drones to improve the supply of grains, storage, and distribution that are essential for their valorization.

2. Food Security and Food Sovereignty in Africa

The agriculture sector contributes 20 to 60 percent of GDP and employs 54% of the labor force in sub-Saharan Africa (SSA), with 70% of rural households depending on it for their livelihood [3]. The sector provides food and nutrition, stabilizes food prices, and provides jobs that stimulates agribusiness, thus contributing to the competitiveness of the economy. Agriculture, therefore, has a fundamental role in ensuring economic growth, social development, food security, and sustainable natural resource management. Despite its vast agricultural potential, Africa has been a net importer of agricultural products in the last three decades. Africa is the most food insecure continent with the highest burden of malnutrition. From 2016 to 2018, Africa imported about 85% of its food from outside the continent valued at \$35 billion, while 73 million people are acutely food insecure [4]. It is alarming that new phenomena like climate change are affecting Africa disproportionately.

Despite its vast agricultural potential, Africa has been a net importer of agricultural products in the last three decades. In 1980, both Africa's agricultural exports and imports were balanced and valued at USD 14 billion, but by 2007 its agricultural imports exceeded agricultural exports by about USD 22 billion [5]. Africa's agricultural imports increased to US\$ 61 billion in 2016. Cereals remain the leading imported agricultural product. In 2001, the main import products were cereals (35%), followed by animal and vegetable fats and oils (9%), sugars and confectionery (9%), and dairy products (5%). In 2016, the main import products were cereals (28%), followed by animal and vegetable fats and oils (11%), sugars and confectionary (9%), and meat and edible offal (6%) [6].

African governments have since the 1980's shifted focus away from local agriculture and food systems in favor of export-oriented agriculture based on a few cash crops like cotton, coffee, cocoa, palm oil, rubber, etc. This was inevitably followed by cereal deficits, imports, and food aid. The current cereal production of 167 million tons in 98 million ha [7] is not sufficient and agricultural growth is not keeping pace with the continent's population growth [8]. Food sovereignty can be better realized by ensuring the active participation of

different segments of the society in value addition to these indigenous food crops through private-public partnerships.

Maize is a major staple food crop in sub-Saharan Africa (SSA) followed by sorghum (22%), then by millets (19%) in terms of total cereal area as shown in Table 1 [7].

Table 1. Cereal supply/demand balance for the 2019 marketing year in Ghana, Nigeria, Uganda, and Namibia.

Balance/Crop	Namibia				Uganda				Ghana				Nigeria			
	Wheat	Rice	Coarse Grains	Total Cereals	Wheat	Rice	Coarse Grains	Total Cereals	Wheat	Rice	Coarse Grains	Total Cereals	Wheat	Rice	Coarse Grains	Total Cereals
Domestic Availability *	16	0	64	80	23	176	3274	3473	0	462	2804	3266	94	5340	21,430	26,864
Import Requirements *	95	24	221	340	360	150	8	518	570	1027	55	1652	4600	2670	420	7690
Consumption Per Capita **	43	10	80	133	9	5	58	72	13	43	64	120	20	35	80	135

* (1000 tons) ** (kg/year). Source: FAOSTAT, 2015; FAO, 2020.

Rice consumption is fast growing owing to rapid urbanization and changes in eating habits [8]. Wheat is grown on around 10 million ha in Africa and is an imported commodity in all of Africa. Africa's agricultural productivity is very low, averaging 300 to 500 kg/ha as compared to 2.5 tons/ha in the United States [9]. Cereal yields in Africa are lower than half of the world's average leading to food insecurity in the continent. Food insecurity is a global crisis, but a serious obstacle to the attainment of sustainable development in Africa. In Figure 1 below, the agricultural production in sub-Saharan Africa is depicted against other developing countries from 1961–2005, it shows a decline in the 1970s in contrast to the other regions despite a rise in the population of the continent. The United Nations Worldometer showed an increase in the African population from 476.4 million in 1980 to 916.1 million in 2005 and currently at 1.35 billion (December 2020). The four African countries (Ghana, Nigeria, Namibia and Uganda) are shown in Figure 2.

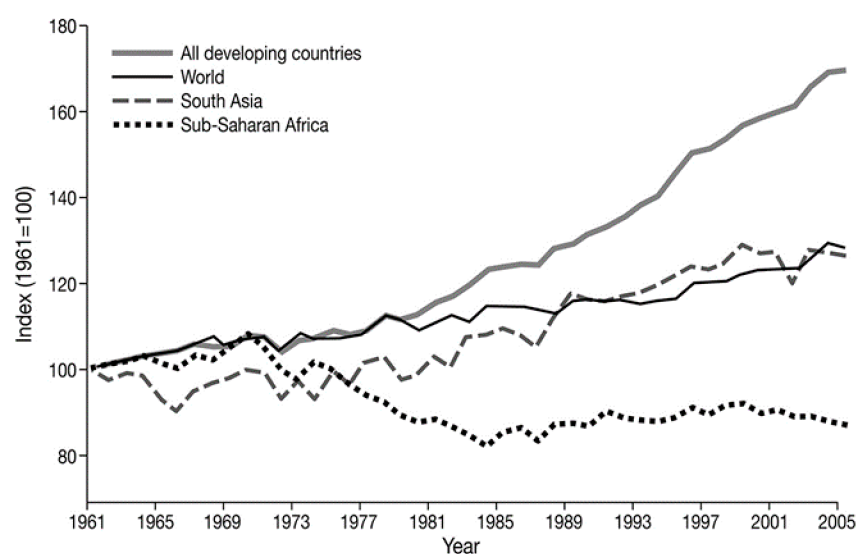


Figure 1. World agricultural production per capita 1961–2005 (index 1961 = 100) [7].



Figure 2. Target countries: Ghana, Nigeria, Namibia, and Uganda are shown in green in the map of Africa.

Challenges to cereal productivity in sub-Saharan Africa include inherently high climate variability, the looming threat of higher temperatures and more vicious droughts, high incidences of diseases, insect-pests, and parasitic plants, and sub-optimal soil nitrogen. Other challenges contributing to food insecurity in Africa are low rural incomes, high poverty levels, high population rate (3% annually) that is not commensurate to the rate of food production, and low investment in mechanization. There are also issues with land degradation, climate change, conflict, low use of fertilizer (African average use is 11 kg/ha compared with the world average of 62 kg/ha), limited use of improved seed, limited access to markets, low level of knowledge, food losses due to pests and diseases in the field, high post-harvest losses, policy orientation, trade imbalances, low use of technology, and lately economic shocks due to COVID-19 [9,10]. These are threatening to undermine the continent's pursuit to achieve the Sustainable Development Goals (SDG) number 2 of ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture by 2030.

On the other hand, Africa has more than 2000 native grains and fruits which hold great potential for the food security question to millions of people in Africa [2]. Since they have evolved in the environment, their genes are more likely to withstand the endemic biotic and abiotic stresses than exotic crop species. The Africa continent is a major producer of several cereals like sorghum, pearl millet, finger millet, teff, and African rice [11], which need to be rediscovered and exploited. Food security and sovereignty can be improved by revisiting these indigenous food crops and their diversified forms to improve nutrition.

The African Union (AU) Agenda 2063 envisioned to improve agricultural productivity through modernization, using science, technology, innovation, and indigenous knowledge, towards a healthier diet for the citizens [12]. In recent times, agriculture has embraced technology to increase the efficiency of food production and reduce food losses. Innovations towards smart solutions and efficient farming techniques are necessary to improve agricultural productivity. Precision agriculture for instance utilizes specialized equipment, software and IT (information technology) services, real-time data, historical data (such as pests' behavior) along with machine learning algorithms to make specific decisions for small areas of the application, rather than pursuing traditional models. These tools give site-specific attention to crops with minimum disruption to the environment, hence

increasing productivity, profitability, sustainability, and protection of the environment. The production of cereal crops in the target countries from 2009 to 2018 is shown in Figure 3 below.

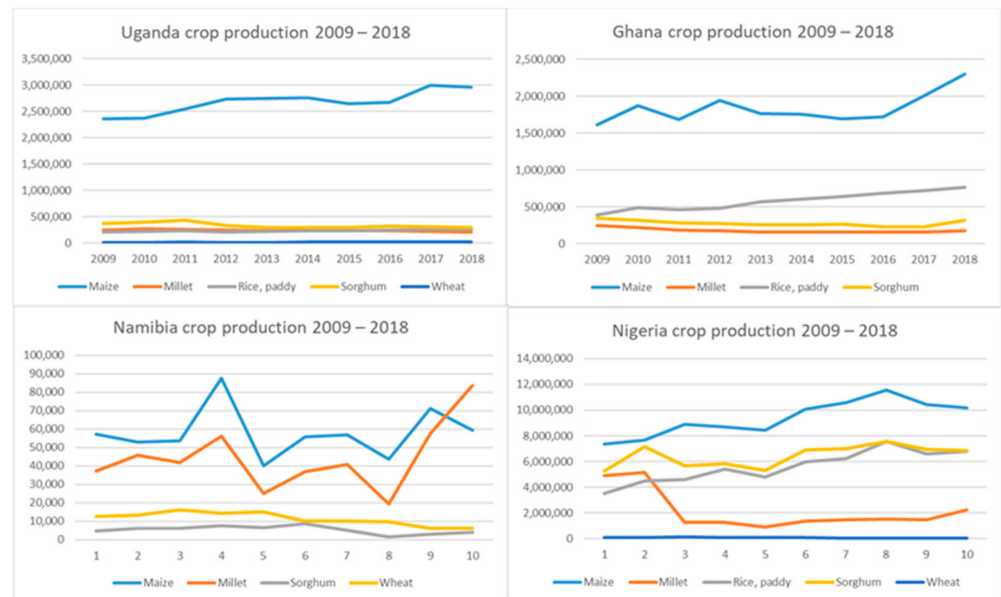


Figure 3. Trends of cereal crop production in target countries 2009–2018.

2.1. Indigenous Cereal Grains and Their Relevance to Food Sovereignty in Ghana

The production of maize, millet, rice, and sorghum are important to ensure food sovereignty in Ghana and other African countries. Agriculture in Ghana is the most important economic sector, employing more than half the population in both formal and informal sectors. It provides food and export products, and almost half of the GDP (8063.21 million Ghanaian Cedis) in the first quarter of 2020 came from agriculture [13]. Agricultural crops, including yams, grains, cocoa, oil palms, kola nuts, and timber, form the base of Ghana's economy.

In Ghana, agriculture is growing very fast and becoming modernized. There are many new technologies being adopted in farming like green-housing and smarter operations. The country's agricultural produce meets the local demands while surplus is exported. For Ghana, export is necessary to earn foreign exchange required to fund importation of essential commodities. The country produces a variety of crops in various climatic zones which range from dry savanna to wet forest and which run in east west bands across the country. As one of the first African countries to liberalize its telecommunication sector, Ghana has made huge progress in ICT infrastructure deployment. One most important method that is being adopted is precision agriculture which allows agriculture producers to use smart methods and modern technology in agriculture production [14]. The use of drones in agriculture is one of the important solutions to control diseases and pests, monitor crops as well as ward away birds.

The Technical Centre for Agricultural and Rural Cooperation (CTA) has been collaborating with leading private sector operators in Ghana since 2017. They organized training on the operations of drones, legislations, regulations, and safety, development of unmanned aircraft systems (UAS) business plans, and networking opportunities. CTA has also invested resources to assess the social acceptance of the technology including its costs and benefits.

Farmers appreciated the benefit of using drones to control fall armyworms as compared to using knapsack sprayers to apply pesticides. They indicated that drones could apply pesticides more accurately to kill the fall armyworm caterpillar, with little or no

chemical wastage—and at a higher speed than a human worker—making the use of drones more effective, simpler, and more efficient.

In a study conducted in Ghana by CTA, majority of the farmers were willing to pay for drone services to control fall armyworms. Drones makes work easier for farmers because it can operate over a wide range of land. Moreover, school children are able to stay at home with their families and do their homework instead of being on the farm. According to CTA, a single drone can scare away birds on a farm as large as three acres (1.2 hectares) [15,16].

2.2. *Indigenous Cereal Grains and Their Relevance to Food Sovereignty in Nigeria*

Agriculture contributes to 40% of the gross domestic product (GDP) and employs about 70% of the working population in Nigeria [17]. The importance of agriculture to the Nigerian economy is evident in the natural endowments of production factors, i.e., extensive arable land, water, human resources, and capital [18]. In Nigeria, 70% of the population are employed in the agriculture sector, which makes it crucial for the development of its economic growth. The major cereals produced in Nigeria are rice, sorghum, maize, and pearl millet [19]. It is ironic that Nigeria is the continent's leading consumer of rice, one of the largest African producers of rice, and simultaneously one of the largest rice importers in the world [18]. The amount of money that Africa's most populous country and largest economy spends on food imports—mostly grains and livestock products—has been rising for decades. It rose from nearly \$2.9 billion in 2015 to \$4.1 billion in 2017, according to Nigeria's National Bureau of Statistics [20]. Apart from the National Economic Empowerment Development Strategies (NEEDS) and the National Food Security Program (NFSP), there have been a number of presidential initiatives on crop modifications and improvements with such crops [21].

2.3. *Indigenous Cereal Grains and Their Relevance to Food Sovereignty in Uganda*

Agriculture in Uganda provides approximately 24% of the gross domestic product (GDP), it generates nearly 48% of export earnings, and provides direct and indirect livelihood support to 80% of all households [22]. Agriculture is thus fundamental to the country's economic growth and transforming the society from being a peasant society to a modern and prosperous country within the next 30 years. The main goal of the Ugandan National Development Plan (NDP III) which covers the period 2020/21 to 2024/25 is to increase average household income and improve the quality of life of Ugandans. In achieving this goal, the agriculture sector is a priority area and one of its strategic objectives is to increase production and productivity. Crop pests among others are identified as the greatest risk to Ugandan agriculture and unless addressed, the Agriculture Strategic Sector Plan objectives are at risk. Pre-harvest losses due to pests and diseases are estimated at 10–20%. The 2014 Ugandan household and population census revealed that approximately two-thirds (69%) of the working population are engaged in subsistence agriculture. The government of Uganda identifies agriculture as a vital growth sector capable of reducing poverty and stimulating economic growth. The key focus is on increasing production and productivity, improving household food security, increasing farmers' income, and increasing the value of exports.

Despite the government strategy to increase production and productivity, a study carried out by New Vision in ten districts of eastern Uganda; Iganga, Mayuge, Bugiri, Busia, Tororo, Butaleja, Budaka, Pallisa, Kumi and Lira, showed that the population of Quelea birds, a type of weaver bird, has reached alarming levels in north-eastern Uganda, posing a threat to the growth of cereal crops [23]. The population of these birds has increased in the fields because of massive encroachment on wetlands that deprived the birds of their natural habitat. The study further revealed that whereas neighboring countries in the region control birds through aerial chemical spraying and use of fire bombs, farmers in Uganda depend on use of traditional methods such as assigning children to scare birds away. In addition, the National Environment Management Authority (NEMA) is opposed to the use of aerial chemical spraying arguing that the chemical could pollute the environment.

Throughout Uganda, farmers' yields of cereal grains are far below what farmers achieve in other parts of the world. Among the reasons for this disparity is that, in addition to a lack of inputs and mechanization, most Ugandan and other African farmers have not been trained to use advanced agricultural practices [24]. Drones have the potential to change the way even small farmers run their farms by providing information they need to implement better practices. In order to evaluate the potential of private sector drone-assisted services as a monitoring system for precision agriculture at the smallholder level, TechnoServe partnered with Equator Seeds Limited, one of the leading seed multiplication companies in Uganda. By using drones, they were able to measure farm area, estimate yields, crop health, and other metrics with the potential to better inform decision-making around farming practices and inputs. This eventually increased farmers' outputs and income.

The introduction of drone technology to aid farmers in scaring birds will also save time for women, who sometimes join children to scare away birds from the cereal crops. Hence, employing drones will enable children to attend school and gain valuable education.

2.4. Indigenous Cereal Grains and Their Relevance to Food Sovereignty in Namibia

The agriculture sector contributes 5% of the Namibian economy, while 70% of the Namibian population is dependent on it directly or indirectly for food, income, and livelihood and it employs a fifth of the workforce [25]. Namibia is the driest country in sub-Saharan Africa with a mean annual rainfall of 230 mm that shows marked regional variations. Beside the low rainfall, the annual potential evapo-transpiration exceeds annual precipitation by ratios of up to 30:1 (not counting the desert areas), hence drought conditions are a common phenomenon throughout most of the country. The harsh condition and limited exploitation of native cereals have led to low domestic production and dependence of imports. Table 2 shows that Namibia imports most of its cereals to feed its 2.5 million people, while Uganda depends largely on domestic cereal production to feed its 42.7 million people.

Table 2. Some African traditionally produced fermented and non-fermented cereal-based foods.

Type	Product	Substrate	Region
Liquid	Ogi	maize, sorghum, millet	Nigeria
	Koko	maize, sorghum, millet	Ghana
	Uji	maize, sorghum, millet	East Africa
	Mahewu	maize meal, wheat flour	South Africa
	Maxau	maize meal	Namibia
	Oshikundu	pearl millet, sorghum	Namibia
	Bushera	sorghum and millet	Uganda
Solid	Agidi	maize, ogi slurry	Nigeria
	Kenkey	maize	Ghana
	Mawe	maize	Benin
	Ugali	maize	East Africa

Source: (Hesseltine 1979; Amadou et al., 2011; Misihairabgwi & Cheikhoussef, 2017) [26–28].

As the driest country in sub-Saharan Africa, and with drought becoming more prevalent, the Namibian climate presents a unique environment where only a handful of crops like pearl millet (*Pennisetum glaucum*) and sorghum (*Sorghum bicolor*) can withstand the heat, poor soils, and meager rainfall [29]. Namibia is left subjected to crop failure and vulnerable to food insecurity and food import. Pearl millet in particular is a hardy, drought-tolerant, heat tolerant crop adapted to poor and saline soils. Pearl millet is a climate-ready crop, and often the only crop that can grow in the arid degraded soils across the drylands of the world including Namibia. Pearl millet is cultivated on about 30 million ha in more than 30 countries across five continents, but Africa and India are leading. Pearl millet grains are

highly nutritious with high levels of metabolizable energy and protein, have high densities of iron and zinc, and more balanced amino acid profile than maize, sorghum, and most vegetables [30,31].

3. The Role of African Youth in Agriculture

The massive ratio of African youth on the continent is an added advantage that needs to be tapped into for the benefit of agriculture and its value chain. To increase food security in Africa, we need to empower small-scale producers and improve agriculture tools. Agriculture can be made more attractive to the youth, for this they will need to be empowered as “agripreneurs” in transforming agriculture. This action, when supported with the right policies at governmental level, will help to strengthen food sovereignty in many African countries. One of the most important solutions is using information and communication technology (ICT). ICT helps to increase production, improve agricultural technologies, markets, banking, and financial services. Training of the youth equips them with skills and activates their creativity towards problem-solving and solutions-orientation for the betterment of the agri-food value chains. Digital solutions that include precision agriculture will help to raise the demand for innovations, while also acting as drivers of agricultural growth and transformation. For example, a project under Farmers’ Hubs targeting young agripreneurs tested new sources of fertilizers such as filao, rice husks, and peanuts shells [32]. The package has the potential to decrease dependency on imported fertilizers, improve farm productivity, and ensure ecosystem sustainability and environmental outcomes of farming activities. The process was facilitated through the Farmers’ Hubs that were provided with incinerators. The youth were also involved in testing alternative materials for seedling trays, such as wood or polystyrene instead of plastic, to reduce their production costs. The Farmers’ Hub model that was developed for eastern and western African countries is an innovation that sparks the interest of not only farmers but also government officials, donors, NGOs, and the media.

Unmanned aerial systems (UAS)—or drone-based systems—have the potential to transform smallholder farming and help increase crop production. The system will appeal to the youth and help in the creation of new skills and jobs. As a tool of precision agriculture, UAS will provide farmers with real-time, actionable data on their land, crop, and livestock to help maximize input efficiency, minimize environmental impacts, optimize produce quality, and minimize risks.

ICT tools help to decide easily and flexibly. For instance, the mobile device is a user-friendly interface with different languages and has immense potential for use by the farmers. The mobile phone provides timely tips and crop advisory from experts for the crops grown by the farmer, pest management, best practices, and most advanced techniques of crop cultivation, as well as the prices and the best practices [31,33]. The impact of ICT on the three main pillars of food security (food adequacy, food availability, and food accessibility) as shown in Figure 4 will help to ensure a sustainable food system and food security.

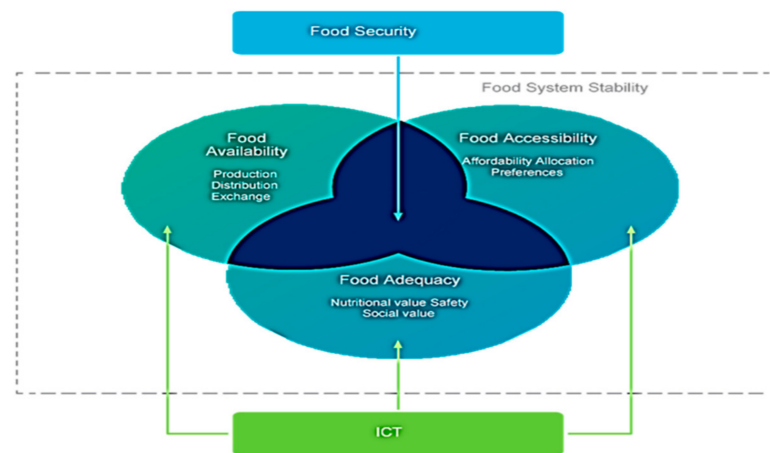


Figure 4. Sustainable food system and information and communications technology (ICT) [33].

4. Processed Products from the Cereal Grains—Fermented and Non-Fermented Products

Grains are the main source of food in Africa including Ghana, Nigeria, Uganda, and Namibia [34]. Most of the native cereal crops like sorghum and millet are heat- and drought-tolerant, hence adapted to climate, and remain the crops of choice in arid areas. At the same time, these crops serve as vital sources of food in Africa, Central America, and South Asia, and they are also used industrially to produce alcoholic beverages and biofuel [35].

Cereal grains have always been an important source of carbohydrates in many cultures of the world. In Africa, there are many staple foods that utilize cereal grains for their diets and they are widely cultivated. The grain products that are regularly consumed come mainly from rice, sorghum, millet, and wheat, and they are produced by farmers both on small and large scales [36]. In Africa, the grains may either be eaten without fermentation or fermented into new products. Cereal grains (sorghum or guinea corn, maize, rice, and millets) are the most important substrates for fermented foods in sub-Saharan Africa. They can be fermented to produce a variety of foods ranging from alcoholic and non-alcoholic beverages, porridges, dumplings, and baked products [37].

Cereal porridge has an international acceptance in many regions of the world. In tropical African countries, several fermented and unfermented cereal foods are consumed daily and they form an essential part of the diet [26]. Despite the dawn of science and technology in Africa, the production of fermented cereal foods is still largely a traditional family art done in a crude manner. The production has not increased substantially and shelf lives are often short [38]. However, in the last few years, there has been a renewed interest to improve this and encourage a better supply of these grains throughout the year that will promote the development of new food products with better quality and safety.

Fermented and non-fermented porridge are common in many African countries as shown in Table 2 [26–28]. They may either be liquid type that are spoon-able or solid types with a higher consistency that are mainly eaten with soup and vegetables.

In other parts of the world, some common types of porridge from cereal grains include the following: atole, made from maize, and sorghum. It is common in Central America. Soven is made from oatmeal and buttermilk and commonly eaten in Scotland. Kiesa is made from oats and popular in Karelia, Finland. Loss of these grains as substrates will lead to food insecurity as the possibility to ferment or process them into edible products will become limited.

There have been talks on revitalizing the agri-food sector in many countries for their potential to create jobs and gainfully employ the teeming youth population. This will happen through digital solutions that are relevant to the agri-sector in the continent. The large arable agricultural land in Africa makes it important for many African countries to ensure a revitalization of this sector with support from the government, public, and private

collaboration. It is essential that agro-allied cottage industries are established in African countries to promote value addition and food processing through public–private initiatives, which will lead to improved employment opportunities, greater wealth, a reduction in migration from rural to urban communities, and improved food security [39]. However, there is an urgent need to reduce cereal grains pre-harvest losses caused by *Quelea* birds estimated to range between 16 and 100% crop losses depending on the country [40].

5. Potential Application of “UAV for Birds on Grains” in Ghana, Nigeria, Uganda, and Namibia

One of the biggest threats to the crop and food security are birds, especially red-billed quelea. The bird can swarm into a cereal field in millions to inflict large losses on rice and sorghum in Africa [41]. The native range of queleas extends over an estimated 9,400,000 km² in Africa [42]; the African countries widely covered includes Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Chad, Congo, Congo, The Democratic Republic of the Côte d’Ivoire, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea-Bissau, Kenya, Lesotho, Malawi, Mali, Mauritania, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Somalia, South Africa, Sudan, Swaziland, Tanzania, United Republic of Uganda, Zambia, and Zimbabwe [43]. Many countries in Africa have not succeeded in eradicating the red-billed quelea because the birds have no respect for national boundaries. The average loss is 15–20% of total cereal production due to bird damage in spite of ignoring the cost when farmers using pesticides to control pests [44,45]. In 2011, it was estimated that the damage caused to small grain crops in the semi-arid zones of Africa was 79.4 million US \$ [46].

There are several methods used by farmers to control the birds, such as catching, scaring away, trapping, and poisoning, collecting eggs, disrupting or destroying the nests, and sometimes burning the birds while roosting. All those methods require costs and continuous daily efforts on the farm for a long time [47].

The traditional methods create disruptions to the birds, which finally die or leave the area and migrate to another place, resulting in an imbalanced ecosystem and a threat to the biodiversity [48]. The birds cause huge losses to crops in the field and are associated with substantial economic and social impacts. Farmers manage to control the birds by using several technologies such as chemical repellent, visual repellent, bioacoustics repellent, and optical repellent. Most of those methods are harmful to the environment and biodiversity [48].

The social consequences are that some bird control methods keep the family busy for a long time, engaging children to scare birds from the field and expose them to missing school and lagging behind in their education.

ICTs provide a tremendous platform for accelerating efforts to achieve the Sustainable Development Goals (SDGs) by 2030 [49]. From this perspective, we can see that unmanned aerial vehicles (UAVs) in Africa, are possibly the most powerful technology for protecting, increasing, and monitoring agricultural production. Unmanned aerial vehicle technology (drone) is a smart innovation that continues to have far-reaching effects across today’s society, transforming the management of food systems from analogue to digital for enhanced food security.

Currently, UAVs have become a low-cost alternative in sensing technology and data analysis techniques. At the same time, UAVs allow farmers to increase efficiency in certain aspects of the farming process such as crop monitoring to planting, cattle management, crop pest control, irrigation mapping, etc. [50]. The capture of images of farmers’ crops with multiple spectral imaging is one advantage of UAV to farmers [50].

Quelea are generally granivores, feeding on seeds of native annual grasses such as *Tetrapogon*, *Echinochloa*, *Urochloa*, *Panicum*, and *Setaria* spp. In the absence of the preferred host, quelea birds attack domesticated annual grasses such as pearl millet, barley, finger millet, proso millet, oat, rice, teff, sorghum, and wheat. *Quelea* birds do not attack maize because of its large seed size [39]. In Uganda, children absent from school to scare away birds from the rice and millet farms. One new solution available by the ministry of agricul-

ture is a ribbon with highly reflective multi-color to scare the birds but the effectiveness of this method is a challenge and untested.

We suggest and explore developing alternative bird-damage control methods (drones scaring) that are low cost, environmentally friendly, and can be easily adopted by farmers. An economical comparison of drones to chemical control: many farmers in Africa use an organophosphate pesticide, Queletox[®] (Fenthion) to kill birds that eat cereal crops at the rate of 2 kg/ha, this will cost \$210 per year for applying this pesticide [49]. Another option is to hire people to scare the birds (3 persons \times 60 days \times \$5 per day) will cost \$900 per hectare per year. On the other hand, when three drones cover 10 hectares and work for 5 years it costs $3 \times \$400 = \1200 and when adding other accessories, the total cost will be \$1500, this is \$300 for 10 ha in a year and will only cost \$30 per hectare per year. For small scale farmers who have small land, less than 2 ha, we suggest a kind of cooperative that neighbor's farmers can share the technologies and in this case the cost divided amongst them. Farmers can also borrow the system from IT companies and the cost and risk will be less. The cost of buying the drone is recovered in the third year and the technology could work for at least 5–10 years. Aside from that, nature is preserved when the birds are scared away instead of being killed; while no risk is posed to the food-chain. This has been further discussed in the potentials and challenges of using a swarm of drones as an intelligent surveillance and reconnaissance (ISR) system in bird scaring targeting weaver birds on pearl millet crops [46].

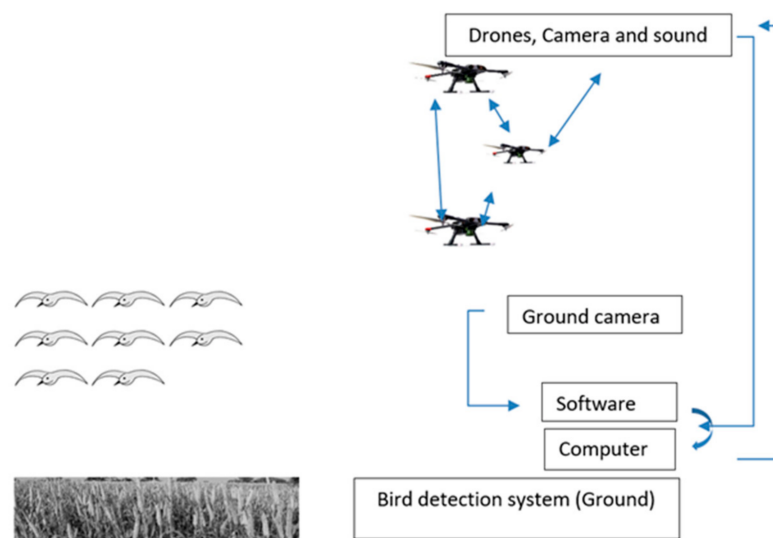
Our idea to use drones to scare birds away from crops (mainly rice and sorghum) in Ghana, Nigeria, Uganda, and Namibia will avoid crop yield losses and boost the availability of food.

Figure 5a shows the invasion of quelea birds on a farm in eastern Uganda destroying sorghum grains before harvest. As shown in Figure 5b above, the system consists of a swarm drone that has coordination and harmony in flying and direction as well as producing voices. Each drone in a swarm is driven by a specific number of spaces and has the ability to vertically fly, take-off, and land (VTOL). We can control the operations by remote control (manually) or autonomously and operate without any human intervention. In this situation, the drone can take off, carry out missions, and land completely autonomously [51].



(a)

Figure 5. Cont.



(b)

Figure 5. (a) Invasion of *Quelea* birds over a sorghum plantation in Ngenge sub-county, Kween district in eastern Uganda (Xinhua/Daniel Edyegu). Picture taken on 6 July 2013 (photo provided by Rhoda Birech). (b) System diagram of the proposed swarm drone bird (Dayoub et. al., 2020).

The technological parts of the proposed drone include electronic speed controllers (ESC), an electronic circuit that controls a motor's speed and direction, flight controller, GPS module, battery, antenna, receiver, cameras, sensors, including ultrasonic sensors and collision avoidance sensors, accelerometer, which measures the speed, and altimeter, which measures altitude [52].

The drone will provide a loudspeaker broadcasting trouble signals, and the design simulates a huge predator bird. It will help to prevent extensive pest birds in a 50 m radius centered on the drone. It is capable of protecting a farm smaller than 25 hectares and when a swarm of drones is used it offers the possibility of protecting large-scale farms.

A drone has a multi-dimensional appearance with visual movement, the alarm sounds released by the drone avoid any bird approaching it. The level of voice will depend on the number of birds, distance, and altitude as well as using different alarms to gain the best effect on birds. It will assess the effectiveness of these alerts when drones are flying within 30 m above ground level (AGL) and at lower altitudes.

In the ground, there will be a sensor with a camera, which investigates the space and determines the time of flying the drones, as well as the system, it saves the data and coordination between swarm drones. In this way, the crops are protected from incoming birds.

There are regulations in using drones, mainly, they need a permit. For operators with a permit, they must ensure that they adhere to the drone laws when flying i.e., the operator must not fly drones over people or large crowds, respect others' privacy when flying your drone, and use it during daylight hours and only fly in good weather conditions. The drones are not flown over airports or in areas where aircrafts are operating, or in sensitive areas including government or military facilities. The use of drones or camera drones in these areas is strictly prohibited.

6. Future Outlook and Recommendations

Digital technologies, along with the right policies and investments, have the power to change the agri-food sector in Africa. There has been a significant growth in the utilization of digitalization for agriculture over the last ten years. However, it has been slow to serve the smallholders that produce 80% of agricultural output in Africa [15].

Ghana has created an environment that is well suited to rapid deployment of digitalization for agriculture, but the existing solutions must be tweaked before their full impact potential will be achieved. In Nigeria, the private sector's role to drive innovative digital transformation of agriculture is a right step in the right direction, but it also illustrates how this development can leave more rural and vulnerable farmers behind. Uganda is increasingly recognizing the role of drones to provide more accurate, up-to-date information on crops being grown in different places as well as data on crop output in a failed season and at bumper harvest. In Namibia, Flying Labs is an innovation hub that brings young robotic enthusiasts together to foster authorized, safe, and responsible remotely piloted aircraft systems (RPASs). The future work of limiting the damage by birds on cereal grains can be incorporated into the planning, design, and construction of rice irrigation systems with the application of drone technology. Similarly, mapping systems can also be improved through a better understanding of how multispectral UAV images can be beneficial in the agricultural farms of these countries. It is highly recommended that the digital savviness of youths and re-trainings in this area will help to increase rural opportunities, that will help young "agripreneurs" to identify new and profitable business opportunities across the entire agricultural value chain.

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