Emerging Technological Issues in African Agriculture: A Systematic Review

Adeolu B. AYANWALE[1]
Oluwole A. FATUNBI[3]
Ayodeji D. KEHINDE[1,2] (✉)
Buruchars ROBIN[3]

Summary

Given Africa's productive potential, addressing constraints to agricultural productivity in Africa will need inventive techniques will need inventive techniques. Having in mind the aforementioned, the study explores the impact of developing concerns in African agriculture, such as maize fall armyworm, cereal aflatoxins, African swine fewer in pigs, and climate change-related issues in agriculture and proposes remedies. This was performed by a scoping review using bibliometrics (Web of Science, CiteULike, and Science Direct) as well as a systematic review covering the years 2008–2021. The findings have revealed that developing concerns have a severe influence on agricultural and food security in Africa, particularly among the poor. Furthermore, the findings have demonstrated that sustainable technologies can address rising difficulties in African agriculture. However, various programs that promote the progress of creative and advanced technology might be implemented to develop frameworks for managing developing difficulties in African agriculture. Production in African agriculture must be boosted by the implementation of innovative and modern technology.

Key words

emerging, African agriculture, technological issue, systematic review

[1] Department of Agricultural Economics, Obafemi Awolowo University, Ile-Ife, Nigeria

[2] Disaster Management Training and Education Centre for Africa, University of the Free State, Bloemfontein, South Africa

[3] Forum for Agriculture Research in Africa No. 9 Flower Avenue, New Achimota Mile 7, Ghana

✉ Corresponding author: kehindeayodeji8@gmail.com

Received: October 4, 2023 | Accepted: May 15, 2024 | Online first version published: July 5, 2024

Introduction

Agriculture remains a critical component of the African economy, accounting for 30-50% of GDP in most countries, providing a primary source of income and livelihood for 70-80% of the population, food supply and revenue from cash crop exports (Kehinde et al., 2016; Ayanwale et al., 2023). Agriculture is one of the areas with the highest potential to provide opportunities for young people, particularly in Africa (Bibbie, 2016; Gaya et al., 2017). According to the International Labour Organization (2017), the agricultural industry employs approximately 54% of Africa's working population. While the region's economies and peoples are diversifying into a variety of other occupations, farming is expected to remain key to incomes and livelihoods for the foreseeable future (Fafchamps et al. 2001; Adeyemo et al. 2017). In comparison to much of the rest of the world, Africa boasts an abundance of the primary natural inputs required for grain and livestock production, including untapped land, labor and water resources so the potential for huge agricultural production expansion is great. However, barely 2 to 3 percent of Africa's renewable water resources are used, compared to 5% globally (World Bank 2013). Furthermore, Africa has low labour costs in comparison to other regions, allowing African farmers to produce many commodities at farm-level costs competitive with those in other countries, with one factor being the much lower average wage for unskilled workers (World Bank 2009, Morris et al. 2009; Kanu et al. 2014). In addition to its big labor force, Africa possesses the world's largest tract of arable uncultivated land and enormous agricultural expansion potential (Kanu et al., 2014; Adeyemo and Kehinde, 2019; Akinola et al., 2023). However, countries have not yet taken advantage of it. As a result, food security has been a persistent issue, with 30% of SSA's population experiencing food insecurity (Pfister et al., 2011; Kehinde & Kehinde, 2020).

According to the Food and Agricultural Organization (FAO) (2015), Africa has the greatest rate of undernourishment in the world, approximately 23.2%. Africa is home to 220 million of the world's 795 million chronically undernourished people. Even in Africa's plentiful regions, food shortages can occur, owing to poor conservation measures or post-harvest losses (Kehinde et al., 2021; Kehinde et al., 2024). The continent is a net food importer, putting extra strain on limited foreign exchange reserves. This is attributable to the fact that agricultural production in Africa has recently stayed lower than in the rest of the globe (Fuglie & Rada, 2013; McCullough, 2017; OECD & FAO, 2016; Amujoyegbe et al., 2018; Ayanwale et al., 2024). Furthermore, most African countries' agriculture remains small-scale, low-technology, rainfed (Kelani et al., 2020; Kolawole et al., 2020; Adeyemo and Kehinde, 2021). This makes farmers and food production systems extremely sensitive to climate, economic and other shocks.

Droughts, cyclones and floods have recently lowered food output, so several African countries are dealing with transboundary insect invasions and animal diseases. Africa's agriculture is one of the most vulnerable to extreme weather events such as drought and floods due to its reliance on rain-fed agriculture, low adaptation capacity and insufficient infrastructure development. Nineteen of the last twenty years have been hotter than any other year on record. In 2020, the Nile and its tributaries continued to overflow. Heavy rains have also caused floods in Uganda, the Republic of Congo, Zimbabwe, and Nigeria. On the other side, East Africa's short rains have resulted in moisture deficiencies in Kenya and Somalia. Desertification, increasing sea levels and other concerns already affect the continent and are expected to intensify in the coming years. Because of climate change, growth and harvesting seasons are becoming more variable. By the end of the century, the continent may lose two of its primary foods; it is anticipated that more than 30% of maize production regions and more than 60% of bean cultivation areas will no longer sustain the crops. Climate change may have a significant impact on African agriculture, but it can be mitigated with climate-smart production technology (Gornall et al., 2010; Ogunleye et al., 2021). Irrigated agriculture, for example, serves as an income buffer against the fall in productivity of dry land farming.

Emerging infectious diseases (EIDs) are another concern in African agriculture. EIDs have occasionally spread to entire nations and even continents, causing hunger and favouring human diseases, socioeconomic disasters and technical issues for agriculture sector management. For example, fall armyworm (FAW), one of the most important maize pests, unexpectedly erupted in Africa in 2016 and expanded swiftly. If FAW is not controlled, it has the potential to reduce maize yields by 8.3 to 20.6 million tons per year (21-53% of production) (Abrahams et al., 2017; Day et al., 2017). Another study based on farmer estimations put FAW infestation rates at 32% in Ethiopia (with production decreases of 934 kg/ha) and 47% (1381 kg/ha) in Kenya (Kumela et al., 2019). The only direct measurement of FAW loss in Africa, from Zimbabwe, indicated losses at 11.6% in 2018, although only in two districts (Baudron et al., 2019). Aflatoxins (AF), which are primarily produced by particular strains of *Aspergillus flavus*, are also discovered in a variety of crops in Africa, including maize. In many African countries, aflatoxins represent major public health risks since their occurrence can be widespread and even extreme. They also considerably impede the expansion of international trade due to rigorous regulation in high-value sectors. The EU has established the strongest limits, stating that no product for direct human consumption can be marketed with concentrations of AF-B1 and total AFs more than 2 mg/kg and 4 mg/kg, respectively (EC, 2007; 2010). Similarly, US laws set the maximum allowable limit for AFs at 20 mg/kg (Wu, 2006). However, if the EU aflatoxin standard is implemented globally, lower-income countries, such as Africa, will face both economic losses and higher expenditures associated with reaching those criteria. This situation necessitates alternate pre- and post-harvest technologies targeted at reducing contamination of commercial foods and feeds, or at least ensuring that AF levels remain within safe limits (Prietto et al., 2015).

African swine fever is another major viral illness of pigs that has posed a substantial danger to global pork supply since 2007. African swine fever virus (ASFV) is most commonly seen in sub-Saharan Africa, where it is considered to have originated in wild warthogs but has since spread to farmed pigs as well. ASF viruses range from highly pathogenic strains that can wipe out an entire herd to less virulent isolates that cause a milder, nonspecific sickness that is difficult to identify as African swine fever. There is no vaccine or effective treatment, therefore badly infected pigs usually die. Many factors contribute to ASFV proliferation, including its long-term persistence in uncooked pork products, which can be fed to pigs in food scraps (pig swill), and its capacity to establish itself in wild or feral SUIDs. Given the aforementioned, there are still other developing concerns that must be addressed using novel ways. However, African farmers are far from the technical frontier, which means there is a lot of room for growth. Given the foregoing, this scoping review investigates the impact of emerging issues in African agriculture, such as the fall armyworm of maize, aflatoxins in cereals, African swine fewer in pigs, and climate change-related issues in agriculture and proposes solutions to these emerging issues. This will be a compendium of existing databases on rising concerns in the African industry. The study also seeks to forecast the relative impact of these concerns before they occur in Africa's agriculture industry.

Materials and Methods

This study is the result of systematic reviews. Contextualized SLR is used to generate bibliographic data, which is then subjected to a variety of bibliometric studies, as described by Zupic and Cater (2015) and Pattnaik and Kumar (2019).

Search Strategy and Data Retrieval Process

Table 1 summarizes the meta-data retrieval process. After identifying a number of often used terms, a broad search phrase is chosen for this study: "Emerging Technological Issues in African Agriculture" which provides access to material from all agricultural disciplines published between 2001 and 2022 and indexed in the Web of Science and Scopus databases. The analysis includes only journal publications in the A*, A, and B categories (Spasojevic et al., 2018; Pattnaik and Kumar, 2019).

Table 1. Bibliographic data retrieval process

Stage	Filtering criteria	Eliminated	Accepted
1	Initial search result (on the search term)	-	940
2	Language filter (English)	12	928
3	Article, Proceeding Paper, review	15	913
4	SCIMAGO index (Q1 and Q2)	82	831
5	Screening based on content	189	107

We use Bibexcel, R and Gephi software to perform the majority of our mapping analysis in this work. Bibexcel and R are used to extract network files, and Gephi is used to visualize bibliometric networks.

Results and Discussion

In this part, we analyze the existing information from published literature on rising technology concerns in African agriculture and provide recommendations. This study comprised 107 studies and six policy documents. Specifically, 80% of the literature reviewed in this study was published after 2008. Such evidence implies that the majority of intellectual debates on developing technological concerns take place in the period following the onset of the issues in African agriculture.

Emerging Issues of Aflatoxin in African Agriculture

Aflatoxins are found in several key food crops, including maize, groundnuts, tree nuts, dried fruits and spices, milk and animal products (Iqbal, Jinap, Pirouz, & Ahmad Faizal, 2015; Mutegi, Ngugi, Hendriks, & Jones, 2009; Perrone et al., 2014). The presence of aflatoxins in grain is primarily due to high moisture content at harvest, insufficient drying and grain storage (Bumbangi et al., 2016). Aflatoxins (AFs) are immunosuppressive, carcinogenic (Kachapulula et al., 2017), mutagenic and teratogenic (Blankson and Mill-Robertson, 2016; Kebede et al., 2020) secondary metabolites produced by fungi (Aron et al., 2017), mainly *Aspergillus* (Eljack, 2012; Maringe et al., 2016; Valencia-Quintana et al., 2020), *Fusarium* (Kebede et al., 2020) and *Penicillium* (Elias, 2016) during storage of contaminated grains. *Aspergillus flavus* and *Aspergillus parasiticus* are more common than other fungus in grains, producing more AFs, particularly AFB1 (Mom et al., 2020). Aflatoxin B1 (AFB1) is the most carcinogenic, mutagenic and teratogenic substance found in foods (Ahmadi et al., 2020; Nesci et al., 2016). It is the strongest known liver carcinogen (Jallow et al., 2018). It was categorized as a group I carcinogen by the International Agency for Research on Cancer. AFB1 is highly stable and can be hazardous at low doses (Ponzilacqua et al., 2018).

Many staple commodities in most underdeveloped countries are at risk from AFB1. Groundnut is the most susceptible crop to AFB1 contamination (Jallow et al., 2018). More than 90% of the food samples obtained by Eshete et al. (2020) from Sidama zone, Ethiopia, have AFB1 levels over the EU legal limit. AFB1 levels in traditionally processed infant food in Ouagadougou, Burkina Faso are 900 times higher than the EU limit of 0.1 µg/kg (Ware et al., 2017). More than 41% of maize market samples in Ghana contain AFB1 levels above Ghana and EU permitted limits (Kortei et al., 2021). Sulaiman et al. (2018) linked urine AFB1 to cereal product consumption. According to Blankson and Mill-Robertson (2016), Ghanaian babies and children consume 0.23 and 0.153 µg/kg/bwd of AFB1, respectively. In addition to AFs, Ezekiel et al. (2021) discovered novel fungus species suspected of producing toxins. Mycotoxin generation is dependent on specific environmental variables; fungi thrive in a humid environment rich in nutrients (Adeyeye, 2016). Other carcinogenic and mutagenic secondary metabolites generated by fungi include cyclopiazonic acid, aflatrem (Ojiambo et al., 2018), ochratoxin A, fumonisins (Sun et al., 2017), deoxynivalenol, zearalenone, T-2 toxin and HT-2 toxin (Kunz et al., 2020). According to a recent analysis, mycotoxin contamination affects 60 to 80% of the world's food crops. These figures are surprising because a large proportion of the world's population is exposed to the risks associated with aflatoxins which cause significant economic losses, interfere with food security and result in a significant decline in agricultural trade between developed and developing countries (WHO, 2018).

AF contamination is responsible for around 25% of global crop loss (Serdar et al., 2020; Ahmadi et al., 2020). However, the hazard is more widespread and severe in developing nations (Udomkun et al. 2017). Mycotoxin contamination is more prevalent in African countries due to low socioeconomic status (Kebede et al., 2020). Wangia-Dixon et al. (2020) found that children from low-income families were more likely to be exposed to AF pollution. Aron et al. (2017) found that around 49% of complementary food samples from Bahi District, Tanzania were contaminated with AFs. A high number of maize, sorghum and millet samples collected in Makueni and Nandi, Kenya, contain AFs and fumonisins above the permitted thresholds of 10 ppb and 2 ppm, respectively (Kang'Ethe et al., 2017). The AF levels in recently harvested groundnuts, beans, cowpeas and Bambara nuts samples from Zimbabwe's Shamva and Makoni areas are worrying and may increase dramatically during storage (Maringe et al., 2016). Blankson et al. (2019) found that 96% of processed infant food sold in Accra, Ghana contained AFs that exceeded the EU permitted level. Obade (2015) discovered that weaning meals routinely used in Kisumu County, Kenya, had levels of AFs exceeding legal limits. Approximately 93% and 42% of household and industrially processed food samples taken from Lagos and Ogun States, Nigeria, are contaminated with mycotoxins, including AFs (Ojuri et al., 2019). Rice and bean samples tested in Enugu, Nigeria, contained AFs beyond acceptable levels (Dozie-Nwakile et al., 2020). Similarly, maize samples taken in Dutsinma, Nigeria, were heavily infected with *Aspergillus fungus* (Mzungu et al. 2018). More than 95% of supplementary food samples from Amhara, Tigray, and Oromia, Ethiopia, were contaminated with AFs (Ayelign et al. 2018). Approximately 72% of infant food samples tested in Accra, Ghana, exhibit AFB1 levels above EU permitted limits (Blankson and Mill-Robertson, 2016). In Nairobi, Kenya, commercial milling centers gathered maize, sorghum, and millet flours with total AFs content of 59.73, 39.21, and 34.80 µg/kg (Wanjeri et al., 2017). Eshete et al. (2020) found AFs over EU allowed limits in 5.3% of breastmilk samples taken from Ethiopia's Sidama zone.

Consumption of AF-contaminated foods is hazardous to human and animal health (Mannaa and Kim, 2017; Ojiambo et al., 2018). The emphasis on the health concerns of consuming AFs in food and feedstuffs has recently expanded significantly. As a result, several experimental, clinical and epidemiological studies have been undertaken to demonstrate harmful health effects in humans and animals exposed to AF pollution, depending on the level of exposure (Sherif et al., 2009). Infants and children exposed to AF contamination may experience poor growth and development (Achaglinkame et al., 2017), vaccination interference (Wangia-Dixon et al., 2020), and iron insufficiency (Opoku et al., 2018). Lower levels of consumption can potentially cause serious health problems such as liver cancer and immunological suppression, and they are highly linked to stunting (Maringe et al., 2016), immune suppression, embryotoxicity and nutritional inadequacies (Granados-Chinchilla et al., 2017). Acute aflatoxicosis can cause bleeding, severe liver damage, edema, even mortality (Mousavi Khaneghah et al., 2018). Aside from aflatoxicosis, food fungal contamination can induce aspergilloma (Dozie-Nwakile et al., 2020) and infections in patients with immune-compromised and hypersensitivity reactions such as asthma and allergic alveolitis (Muhie and Bayisa, 2020). Furthermore, when Hepatitis B and Hepatitis C carriers are exposed to aflatoxin, they are at high risk of getting liver cancer, which is expected to kill up to 26,000 people in Africa south of the Sahara each year (Dozie-Nwakile et al., 2020).

According to literature, this review study discusses various potential options for controlling aflatoxins in Africa (Udomkun et al., 2017; Mir et al., 2021). This section discusses the following:

I. Pulsed Light

Pulse light is a promising method for grain decontamination. It has the potential to be a viable alternative to existing methods while having minimal impact on grain quality. However, pulse light has a low penetration rate through the grain, lowering the germination percentage of sprouting seeds (Maftei et al., 2013). Pulsed light's decontamination efficiency is related to its broad UV spectrum, short flashes and peak power (Wang et al., 2016; John and Ramaswamy, 2018). Pulsed light is a low-cost, non-thermal approach that leaves no trace on food. Many food material parameters, including matrix and thickness, content and mycotoxin type, may influence pulsed light treatment (John and Ramaswamy, 2018). Pulsed light processing settings have a significant impact on treatment efficiency and are determined by the number of pulses employed, their power and the distance between the lamp and the sample during treatment. Maftei et al. (2013) used pulsed light to decontaminate wheat grain. The grains were subjected to pulsed light therapy for up to 40 flashes of fluence at 0.4 J/cm^2, with a total energy release ranging from 6.4 to 51.2 J/cm^2 per pulse. At higher dosages, the pulsed light demonstrated effective microbial reduction (4 log cycles) (51.2 J/cm^2 per pulse). Wang et al. (2016) investigated the effects of pulsed light treatment on the degradation of aflatoxin B1 and B2 in rough rice. Rice samples were treated with 0.52 J/cm^2/pulse for 20, 40, 60, and 80 seconds at room temperature. Pulsed light treatment in the 1980s lowered AFB1 (75%) and AFB2 (39.2%). Aflatoxin B2 was more resistant to breakdown by pulsed light therapy than aflatoxin B1. The variance in the degradation capacity of various mycotoxins is caused by differences in their molecular structures, which alter photodegradation efficiency. In another study, Zenklusen et al. (2018) used pulsed light treatment on malted barley. The maximum reduction of *A. carbonarius* and *A. flavus* was seen after 5-15 seconds of treatment time. Chen et al. (2019) employed intense pulsed light to decontaminate deoxynivalenol in raw and germinated barley.

II. Sorting Technology

The use of computer-based image processing techniques is one of the most promising approaches for large-scale screening of fungal and toxin contamination in food and feed. Furthermore, Fernandez-Ibanez et al. (2009) described the NIRS methodology as a quick and nondestructive method for identifying mycotoxins such AF-B1 in maize and barley at a concentration of 20 ppb. Nonetheless, NIRS generates an average spectrum that lacks spatial information from the sample regarding the distribution of chemical composition. Hyperspectral imaging (HSI) is another approach for monitoring the distribution and composition of mycotoxins in contaminated food samples, particularly grains. This approach may generate both localized information and the entire NIR spectrum in each pixel (Manley et al. 2009). Yao et al. (2010) employed hyperspectral imaging (HSI) techniques to determine AF contamination in maize kernels infected with *A. flavus* spores. Wang et al. (2015) have demonstrated the potential of Vis/NIR-based HSI for quantifying and distinguishing AFs in infected maize kernels. Ozlüoymak (2014) proposed another image-based sorting approach, reporting that roughly 98% of the AFs in infected figs were successfully detected and separated using a UV light and a color detecting system. This method relied on the survivability of bright greenish-yellow fluorescence (BGYF), which is produced by *A. flavus* through the oxidative activity of peroxidases in living plant tissues.

III. Ozone Fumigation

Ozone, a triatomic form of oxygen (O3), is one of the most effective disinfectants and sanitizers. It has been classified as Generally Recognized as Safe (GRAS), which means it can be used directly as an antibacterial agent in the food sector. Normally, ozone can be produced via a variety of processes, including electrical discharge in oxygen, electrolysis of water, photochemical and radiochemical. One of the most appealing aspects of ozone is that, once its half-life has passed (20 to 50 minutes), breakdown products pose no threat to the treated materials (Karaca and Velioglu, 2014). To inhibit bacterial development during post-harvest treatment, gaseous and aqueous ozone phases are used (Zorlugenç et al., 2008). Ozone has potential applications in the food business as a disinfectant (Trombete et al., 2017; Pandiselvam et al., 2018). Ozone is a strong oxidant used to remove mycotoxins from food grains (Mendez et al., 2003; Savi et al., 2020). Ozone treatment is a viable alternative to standard decontamination treatments that does not leave hazardous residues and is environmentally beneficial (Pandiselvam et al., 2018). However, the ozone procedure is quite expensive due to the advanced cleaning technology (Luo et al., 2014). Aflatoxin breakdown by ozone begins with an electrophilic attack on the furan's C8-C9 double bond, resulting in the creation of primary ozonides, which are then rearranged into monoxide derivatives such as aldehydes, ketones, and organic acids (Diao et al., 2013; Pankaj et al., 2018).

IV. Packaging Materials

Packaging materials are commonly viewed as the final stage of product development in post-harvest management to extend the preservation of food and feed products. A variety of environmental factors, including temperature and humidity, as well as light and oxygen exposure, can have an impact on food commodities throughout storage and delivery. Overall, these components have been shown to facilitate a variety of physicochemical changes, including nutritional degradation and browning processes, the latter of which produce undesired colour changes. The interplay of these conditions can also increase the probability of fungal growth and eventual AF contamination (Giorni et al., 2008). Many smallholder farmers in low-income countries customarily store agricultural items like grains in containers made of wood, bamboo, thatch or mud, which are then covered with thatch or metal roofing sheets (Waliyar et al. 2015). Metal or cement bins have recently been introduced as alternatives to traditional storage systems, but their high cost and difficulty in accessibility limit adoption by small-scale farms (Hell and Mutegi, 2011) slow down their use. Several studies have reported the use of Purdue Improved Crop Storage (PICS) bags to reduce fungus development and AF contamination. Williams et al. (2014) found that PICS bags effectively reduced the establishment of *A. flavus* and the subsequent AF contamination in maize across a wide range of moisture levels when compared to non-hermetic containers. These findings are consistent with Njoroge et al. (2014), who reported that grains stored in PICS bags absorbed less moisture than grains stored in woven polypropylene bags. In Benin, Ghana, Burkina Faso, and Nigeria, Baoua et al. (2014) they stored locally contaminated corn in PICS bags. Although 53% of maize had AF levels above 20 ppm, samples from PICS bags showed less accumulation than those from woven bags.

Emerging Climate-Related Issues in African Agriculture

Africa is seen as the "rising continent" of the twenty-first century, thanks to its abundance of natural resources such as oil, gas, gold and diamonds, as well as its increasingly educated people. Similarly, the impacts of climate change on African countries are increasing, resulting in climate-related calamities. Africa is thought to be the continent most sensitive to climate change effects (Porter et al., 2014). It is difficult to determine how much these effects can be attributable to more severe or frequent disasters caused by climate change. Accelerated global warming and climate change have already had a negative impact on African livelihoods and food security. Over the previous 50 to 100 years, land surface temperatures in most of Africa have increased by 0.5 °C to 2 °C. In July 2018, the city of Ouargla in Algeria's Sahara Desert had the highest temperature ever accurately recorded in Africa: 51.3 °C.

Sea levels have increased, allowing saltwater to enter the freshwater systems that people rely on for drinking water and agriculture. Saltwater incursion has already had an impact on Egypt's Nile Delta, which feeds 80 million people. Over the past 30 to 60 years, Eastern Africa has seen an upsurge in droughts and storms. By 2050, the average temperature in Africa is expected to climb by 2 °C from current levels, with Southern Africa becoming drier and Eastern and Western Africa experiencing more intense episodes of rain and drought. The IPCC has identified the Sahel and tropical Western Africa as 'climate change hotspots'. The two regions are expected to experience extraordinary conditions between the late 2030s and early 2040s, earlier than anywhere else on Earth. The Sahel, one of the world's most environmentally damaged regions, is expected to see 50% higher average temperature rises than the worldwide average. Drought is anticipated to cause arid and semi-arid regions of Africa to expand by 5-8%, or 60-90 million hectares, resulting in agricultural losses ranging from 0.4-7% of GDP in Northern, Western Central, and Southern Africa (IPCC, 2008; Kehinde, 2020). Extreme heatwaves and flooding will hit Northern Africa in the next decades as a result of sea-level rise and food shortages. These proposed reforms are predicted to increase existing high levels of food and water insecurity, poverty and poor health, as well as stifle economic development (Dasgupta et al., 2021). According to recent studies, Tunisia can expect 10-50% decline in wheat yield at 2 °C of warming. Climate change will exacerbate water scarcity in Northern Africa, but population expansion, increased reliance on irrigation and other land use changes are all projected to have a substantial impact.

Adaptation will have to be a priority for climate policy on the continent this century, with 'adaptation' referring to measures at all levels to increase resilience and minimize susceptibility to the effects of climate change. There is currently a fast growing corpus of literature on adaptation at the family and community levels in Africa (Wellard et al., 2012; Franzel et al., 2019). Adaptation in Africa has numerous problems, including technical, political, institutional and organizational, economic, social and biophysical aspects. As an example, improving estimates of climate change consequences is critical for adaptation (Katz et al., 2013), however many African countries are hampered by a lack of historical weather and climate data (Conway and Schipper, 2011). Adaptation necessitates institutional leadership to develop policies and programs to respond to future risks, catalyze stakeholder interest and action, and distribute resources (Ford and King, 2015; Smith et al., 2009), but institutional failure in rural extension services, as well as a failure to consider emerging problems from climate risks, have been identified as region-wide barriers. The costs of adaptation are further influenced by major development deficits, with some estimates indicating that the costs of adaptation in Africa might surpass $50 billion per year (UNEP, 2015). According to a new UNEP report, the cost of adaptation in developing countries, including Africa, is expected to be between $280 and $500 billion per year by 2050 (UNEP, 2016), implying that the cost of adaptation in Africa may exceed $100 billion per year by that time. While adaptation financing from the United Nations Framework Convention on Climate Change (UNFCCC) may assist offset some of these costs, it is insufficient for climate-proofing (UNEP, 2015).

Current levels of international adaptation financing are insufficient, with roughly USD$1-2 billion flowing to Africa each year for adaptation, compared to a predicted requirement of around USD/year by 2030 (UNEP, 2015). This study emphasizes that the necessary money to realize the capacity to conduct adaptation projects on the appropriate scale remains a constraint. To guarantee that allocated climate and environmental money is channeled to smallholders, IFAD developed the 'Adaptation for Smallholder Agriculture Programme' (ASAP) in September 2012 to strengthen IFAD-supported programs, which had mobilized US$ 366 million as of September 2015. ASAP is now the world's largest adaptation initiative for smallholder farmers, working within the broader IFAD mandate to help poor rural people improve their food security and nutrition, increase their incomes and build resilience. The IFAD Executive Board has devised and authorized ASAP investments in low and lower-middle-income African nations totaling US$ 2-15 million per project. Many nations lack financial plans to support CSA adoption, despite the fact that transitioning to climate-smart agricultural growth paths necessitates new investments (Mapfumo et al., 2015).

First, investments are required to improve climate data, scenarios and effect models. This necessitates new approaches and partnerships among key UN agencies (including UNFCCC, UNDP, World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), Food and Agriculture Organization (FAO), International Fund for Agricultural Development (IFAD), the African Centre for Meteorological Applications for Development (ACMAD), and national governments to identify the main problems across various sectors and develop partnerships with relevant stakeholders. Climate data needs to be reinforced by financing various meteorological organizations in African countries to collect, manage, store and analyze climate data, as well as distribute information in a way that diverse sectors of the economy demand on an ongoing basis. Strengthening the observation network is critical for forecasting, projecting and comprehending Africa's distinct climate and vulnerability to the effects of climate change (Conway and Mustelin, 2014; Niang et al., 2017). This means engaging local people and decision-makers to include their knowledge of climate conditions, observed changes and vulnerability determinants (Ford et al., 2016; Savo et al., 2016). An African research network program that links local communities, farmers, researchers and meteorological departments should be promoted for data collecting; similar models have been recommended for other data-poor countries (Huntington and Smith, 2011). This evaluation proposes that African scientists increase their ability in areas such as software training and artificial intelligence, while also addressing training costs and associated hazards. At this stage, we recommend technological adoption above comprehensive technological innovation for three reasons. For starters, given the impending climate change and Africa's overall fragility, developing technology from the ground up may not be a practical and successful alternative. Again, the time required to create, test and deploy new and working technologies is typically longer than anticipated, and new technologies may not be available for use when needed. Finally, access to expert information based on previously proven and deployed technology is now available. The assessment also suggests that African scientists collaborate with their colleagues to facilitate effective technology transfer. Previously, scientific conferences and expeditions were the primary venues for scientific interchange and collaboration. Recently, social media and other online platforms have emerged as key drivers in the democratization of knowledge, including science. African scientists can also leverage social media platforms to establish a strong scientific presence and help the formation of scientific alliances.

The Emerging Issue of Fall Armyworm in African Agriculture

Fall armyworm was previously thought to be found solely in the Americas, but it was discovered in numerous West African countries in 2016 and has subsequently spread, causing major outbreaks with significant feeding damage on maize farms (Nagoshi et al. 2017). FAW was initially discovered on the African continent in 2016 (Goergen et al., 2016; FAO, 2017; Day et al., 2017; Harrison et al., 2019), and outbreaks have been reported across West and Central Africa, including Botswana, the Democratic Republic of Congo, and Ghana. FAW rapidly spread from West and Central Africa, wreaking havoc on maize crops in Kenya, Malawi, Namibia, South Africa, Swaziland, and Zambia (Goergen et al., 2016; Abrahams et al., 2017; Midega et al., 2017). In February 2017, the fall armyworm moved to Ethiopia, Tanzania and Zimbabwe (Midega et al., 2018). As of December 2017, 54 African countries had been studied, and FAW was determined to be rapidly expanding, having reached around 38 African countries (Westbrook et al., 2016; FAO, 2017; Harrison et al., 2019). FAW is one of the most devastating pests in terms of livelihood loss and economic impact in high-income nations, let alone underdeveloped countries, where it causes significant damage to maize and other crops (Hailu et al., 2018). Kenya has lost 15,000 acres of maize to FAW, worth Shilling 1.3 billion (Oketch, 2018). Similarly, this insect caused significant harm to maize output in other Eastern nations (Gebreziher 2020). *S. frugiperda* has been regarded as one of the most destructive pests to African agriculture, which is already hampered by droughts, low soil fertility, poor maintenance and pests and diseases (CABI

2017). *Spodoptera frugiperda* caused maize losses ranging from 8 to 21 million tons per year in 12 African nations, totaling up to US$6.1 billion and affecting approximately 300 million Africans (Midega et al. 2018). The recent study from 12 African nations discovered that fall armyworm could cause an annual yield loss of 4.1-17.7 million tons of maize (Rwomushana et al., 2018), valued at US$ 2.5-6.2 billion (Conrow, 2018). Fall armyworm is estimated to cause a yield loss of 22-67 percent in Ghana and Zambia (Day et al., 2017), 47 percent in Kenya (Kumela et al., 2019), and 9.4 percent in Zimbabwe (Baudron et al. 2019). In Ghana, the current average maize loss was found to be 26.6%, which equated to an annual value of US$177 million, significantly lower than the loss in 2017 (Rwomushana et al. 2018). Togo's information is not yet available. This insect has caused problems for farmers all over the world because of its ravenous feeding habits on maize, rice, sorghum, sugarcane, millet, cotton and vegetables such as tomatoes and crucifers.

Since the FAW's introduction in Africa, various studies, overviews, and guidelines have been published, but no systematic, quantitative nationwide study has been conducted in any of the afflicted nations. Because FAW was a new pest to Africa, the earliest publications on its invasion were manuals that documented the scope of the problem and its potential impact while also providing management strategies. These articles originated from international organizations working in the subject, such as the Food and Agriculture Organization (FAO, 2017, 2018) and the International Maize and Wheat Improvement Centre (Prasanna et al., 2018). Because of the significant potential losses produced by FAW, several control strategies have been proposed (Hailu et al., 2018; Kumela et al., 2018; Midega et al., 2018; Harrison et al., 2019; Ahissou et al., 2021; Hussain et al., 2021; Nyamutukwa et al., 2022).

Parasitoid

They lay eggs on egg masses, larvae and adult fall armyworms and stop their growth by growing on them. Egg parasitoids are regarded the most essential biological controllers because they prevent agricultural damage and may be grown in large quantities (Prasanna et al., 2018). The Nepal Agriculture Research Council recently discovered fall armyworm egg parasitoids, which were nearly identical to numerous specimens in the Gene Bank (GC et al., 2020). *Cotesia icipie* is an essential larval parasitoid that can kill more than 60% of autumn armyworms (ICIPE, 2018).

Entomopathogens

Plant pathogens (viruses, fungus, protozoa, bacteria, and nematodes) are generally damaging to crops and have an important role in limiting crop output, although some of them control the FAW population in the field (Assefa and Ayalew, 2019). Nuclear Polyhedrosis Viruses (NPVs) can be a valuable and successful technique for controlling fall armyworms (de Romero et al., 2009). Nuclear Polyhedrosis Viruses (NPVs) such as the *Spodoptera frugiperda Multicapsid Nucleopolyhedrovirus (SfMNPV)*, fungi such as *Metarhizium anisopliae*, *Metarhizium rileyi*, *Beauveria bassiana*, *Protozoa*, and bacteria such as Bt bacteria all have a natural effect on FAW (FAO, 2018).

Botanical Pesticides

Botanical pesticides are pest-controlling compounds derived from various plant species and plant groups. Botanical insecticides are environmentally friendly, less hazardous to farmers and consumers, and safe for natural pest predators. Fall armyworms can be managed using the seeds or leaves of plants from the *Meliaceae* family (*Azadirachta*) and the *Asteraceae* family (Pyrethrum). The use of 0.25% Neem oil extract in a laboratory setting resulted in 80% larval death. After 72 hours of treatment, botanical extracts of *Azadirachta indica*, *Schinnus molle*, and *Phytolacca dodecandra* resulted in the highest larval mortality (>95%) (Sisay et al., 2019). *Azadirachta indica* seed cake extracts (Silva et al., 2015) and methanol extracts of roots and other aerial parts of *Myrtillocactus geometrizans*, as well as a plant oil extract from turmeric, clove, and palmarosa, have significant effects on controlling the second instar of fall armyworm larvae (Barbosa et al., 2018). Ethanol extracts of *Argemone ochroleuca* have larvicidal characteristics because they impair larvae's eating ability.

Chemical Control

Chemical pesticides are synthetic chemical compounds used to kill or repel invasive insects and pests that damage crops. Different insecticides and pesticides have been shown to be effective against FAW. However, the use of pesticides is not the primary concept of IPM, but chemical pesticides are utilized under extreme conditions. Their usage is advised with caution so that the risk to the environment and humans is kept to a minimum. Soybean seed treated with Chlorantraniliprole and Cyantraniliprole requires less foliar spray to control autumn armyworms. Some synthetic chemical pesticides, including methomyl, cyfluthrin, and methyl parathion, can be used to suppress fall armyworm infestations (Tumma and Chandrika, 2018). Pesticides should be used with caution due to their toxicity, persistence, tendency to accumulate and biomagnification. Methomyl, Chlorpyrifos, Carbosulfan, Beta-cypermethrin, Spinetoram, Emamectin benzoate, Indoxacarb, Cartap hydrochloride, Lufenuron, Diflubenzuron, Chlorantraniliprole, and other chemicals are commonly used in South Africa to control fall armyworm in maize, cotton, sorghum, potatoes, crucifers, and other vegetables (IRAC, 2018). Emamectin benzoate 5 SG showed the highest acute toxicity, followed by Chlorantraniliprole 18.5 SC and Spinetoram 11.7 SC by leaf-dip bioassay method, whereas Chlorantraniliprole 18.5 SC, followed by Emamectin benzoate 5 SG, Spinetoram 11.7 SC, Flubendiamide 480 SC, indoxacarb 14.5 SC, Lambda cyhalothrin 5 EC, and Novaluron 10 EC are effective by field efficacy for two planting dates (Jun and Sept sown crop) for control of second instar larva.

Emerging African swine fever in Pigs

African swine fever (ASF) is a highly contagious swine disease caused by infection with the African Swine Fever Virus. ASF has been found primarily in sub-Saharan Africa, where it lives in a sylvatic cycle and/or among domestic pigs. ASF is disseminated through contact with infected animals' bodily fluids. It can be transmitted by ticks that feed on afflicted animals. People might potentially spread the virus by carrying it in their vehicles or clothing. It can also be transmitted by feeding pigs uncooked waste containing diseased pork products, while there are state and federal standards in place to guarantee that garbage feeding is done correctly and does not spread disease. ASF symptoms include a high fever, decreased appetite, weakness, red, blotchy skin or skin lesions, diarrhea, vomiting, coughing and difficulties in breathing. Producers should promptly report animals exhibiting any of these symptoms to state or federal animal health officials for testing and inquiry. Timeliness is critical for stopping the spread of ASF. It generates significant economic losses, jeopardizes food security and reduces pig output in affected countries. In Africa, ASF has the potential to devastate both the commercial and subsistence pig production sectors, but the poorer pig farmers are more likely to apply effective prevention and control techniques as well as basic biosecurity. In places like Cote d'Ivoire and Madagascar, the introduction of ASF resulted in the extinction of 30 to 50 percent of the pig population. ASF also has substantial consequences for food security, as pig rearing is a major source of human dietary protein in many nations, particularly in areas where beef production is problematic.

ASF poses a severe danger to people's food security and livelihoods. African swine flu is not a new issue. It is a severe problem that has not received adequate attention. African swine disease can cause up to 100% morbidity in newly domesticated pig herds. The virulence of the isolate determines cumulative mortality, which might range from less than 5% to 100%. It is frequently between 30 and 70% in subacute instances. However, viruses can take days to weeks to spread throughout a herd, and early herd mortality rates may be modest even when the case fatality rate is high. Less virulent isolates are more likely to kill pigs with other illnesses, pregnant or nursing sows, and young animals. When ASFV is brought into new regions, morbidity and mortality rates tend to rise, with an increased incidence of subacute and subclinical cases once endemic. However, certain African pig populations are reported to be more resistant to African swine fever than others, while the reason for this resistance is unknown. African swine fever can only be treated with supportive care. Many ordinary disinfectants are ineffective against ASFV; therefore, it is recommended to use a disinfectant that has been specifically licensed for this virus.

Sodium hypochlorite, citric acid and certain iodine and quaternary ammonium compounds have been shown to kill ASFV on nonporous surfaces. In one experiment, both 2% citric acid and higher quantities of sodium hypochlorite (e.g., 2000 ppm) could disinfect the virus on wood; nevertheless, citric acid was more efficient. To inactivate ASFV in unprocessed meat, heat it to at least 70 °C (158 °F) for 30 minutes. Serum and bodily fluids can be inactivated in 30 minutes at 60 °C (140 °F). Viruses in serum-free medium can be inactivated at pH < 3.9 or > 11.5. With no cures available, combating ASF necessitates the slaughter of millions of animals, putting additional strain on the global pork economy. The only method to eradicate this terrible disease is to depopulate all infected or vulnerable swine herds. There are no commercially available vaccinations for ASF. Vaccines have been tested in other countries but have failed to protect animals from the disease (USDA, 2019). In 2019, APHIS (2020) allocated $5.2 million to the prevention, detection and response of animal disease entering the United States. It is difficult to estimate the financial impact that ASF could have if it entered the United States. For example, one analysis forecasts that the pork industry would lose $1-7 billion per year (Lusk, 2019). Plum Island researchers have recently revealed in the Journal of Virology that they have developed an experimental vaccination capable of conferring immunity against ASF in pigs. This vaccine shows great promise for preventing ASF because it was tested against the viral strain responsible for the most recent outbreaks (Borca et al., 2020). This brings us one step closer to eradicating a disease that threatens the livelihoods of farmers in Africa.

In the future, it may be possible to improve ASF management by using effective new-generation vaccinations and/or taking advantage of inherent resistance found in some domestic pig populations. Meanwhile, we face the challenge that traditional control methods such as 'stamping out' and destroying large numbers of pigs are becoming increasingly unacceptable for ethical and environmental reasons, and are impossible to successfully implement in countries with limited financial and veterinary resources. The only realistic alternative is farmer-based control, which focuses on prevention. A directly transmitted illness, such as ASF, can be adequately controlled by biosecurity measures; however, applying these in the areas most afflicted by ASF requires a shift from traditional extensive low-input husbandry to more intensive systems that place a greater demand on the producer. Such a reform would have to be market-driven rather than solely based on disease prevention considerations.

Additional research is needed to create effective vaccinations (Urbano and Ferreira, 2022). The discovery of ASFV genes implicated in virulence and immune evasion (Dixon et al., 2008) enables the production of rationally attenuated vaccines through successive deletion of these genes possible. However, substantial testing of the vaccines' safety is required before they are used in the field. A safer alternative would be to create ASFV vaccinations that are faulty and do not replicate. These techniques offer the advantage of expressing a large number of antigens without requiring prior knowledge of which are protective; nonetheless, vaccine production requires high containment facilities. Alternative techniques based on the expression of protective antigens are viable, but they must first be identified. The advent of high-throughput technologies for creating recombinant viral vectors paves the way for a global assessment of the protective potential of all ASFV-expressed genes (Zhang et al., 2023). The genetic variety of ASFV strains circulating in several areas is a source of worry for the use of vaccinations. Recent investigations have shown cross-protection between distinct genotypes, raising the possibility of developing vaccines that might protect against infection with several genotypes. In other areas, isolates of only one genotype are also present. These include West and Central African countries (genotype I), the broad endemic region comprising Malawi and Zambia (genotype VIII) and the Caucasus and Russia (genotype II). Capacity building is also required to increase regional and national laboratories abilities to confirm suspicious cases and support surveillance actions.

Emerging Water Scarcity in African Agriculture

Water is a key driver of agricultural output. The availability of excellent water immediately influences agricultural operations such as crop and livestock production, fishing and agro-processing. Water scarcity can pose substantial dangers to Africa's smallholder agricultural system by reducing yields (Namara et al., 2010). Globally, it is estimated that by 2050, around 66% of Africa's population would be subject to water scarcity. Such shortages will have a significant impact on food production because agriculture consumes a big percentage of fresh water, with SSA among the most affected regions (Gashu et al., 2019). Half of SSA's territory is dry or semi-arid, with little precipitation and significant evaporation rates. However, a substantial portion of the region's population relies on rain-fed agriculture, which provides around 90% of the basic food. Furthermore, livestock production, which is subject to increasingly unpredictable precipitation, is one of the most important economic sources in SSA (Cooper et al., 2008). By 2025, 22 of 28 countries in SSA may confront water scarcity (Gashu et al., 2019). Furthermore, it is anticipated that even by the year 2050, per capita water availability in Eastern and Southern African countries will fall below the minimal requirement (1000 m^3/capita/year), while West African countries will have 1000-2000 m^3/capita/year (Wallace, 2000). Although the potential impact of water shortage on agricultural output can be significantly minimized by using adaptive mechanisms, the cost of dealing with changing weather conditions and adapting to climate change could exceed 5-10% of GDP. In addition to the projected effects of climate change, increased population growth combined with climate change may exacerbate water scarcity (Cooper et al., 2008). Developing and executing adaptive techniques to deal with the challenge of water shortage are becoming increasingly important in the agriculture sector. Agricultural policy today appears to push for increased use of irrigated agriculture, which is less vulnerable to climate change and may be a better alternative for water efficiency than rain-fed agriculture (Molden et al., 2007). To respond to water constraint, Rijsberman (2006) proposes enhancing institutional, agronomic, technological and managerial aspects that favorably improve water efficiency by lowering water loss through storage and regulating runoff and drainage.

Emerging Soil and Land Issues in African Agriculture

Poor soil health poses a significant danger to the long-term viability of crop and livestock productivity systems around the world. Soil degradation in agricultural systems is caused by suboptimal management methods that result in losses in soil biological, chemical, and physical quality, lowering the soil potential to support production and environmental services. Soil degradation has the greatest impact in Africa, where around 65% of land is classed as degraded (Vlek et al., 2010; Zingore et al., 2015; Kehinde et al., 2022; Oyenpemi et al., 2023). The frequency of severely deteriorated soils is extremely high. It covers approximately 350 million ha, or 20 to 25% of total land area, with approximately 100 million ha believed to be highly degraded, primarily due to agricultural activities. Soil degradation costs SSA around $68 billion per year, reduces regional annual agricultural GDP by 3%, and has an impact on the livelihoods of the majority of the population, who rely directly on agriculture for food and income. Cereal crop yields in SSA have remained stagnant at less than 1.5 t/ha for the past five decades, despite the fact that most crop varieties have a yield potential of more than 5 t/ha. Yields for legumes have remained stagnant at less than 1 t/ha, despite potential averages of more than 2 t/ha. As a result, unlike other parts of the world, SSA's per-capita food output is declining, exacerbating food and nutrition insecurity and poverty. Some of the most rapidly degrading locations are densely populated areas with favorable weather and generally fertile soils throughout much of Eastern and Central Africa's highlands. The primary causes of soil degradation in SSA are water erosion, wind erosion, and deterioration of physical, chemical, and biological properties (Muchena et al., 2005). Many degradation processes occur concurrently with negative impacts on biological productivity and the environment due to smallholder farmer management practices.

As farm holdings fall, smallholder farmers respond by farming their fields year after year, with no crop rotation or other long-term practices to preserve or improve soil health. The implications include severe soil degradation throughout the region (Kehinde, 2022). According to a 2014 Montpellier Panel analysis, around 65 percent of arable land in Sub-Saharan Africa has already been degraded, costing more than 180 million smallholder farmers approximately US$ 68 million in lost income per year. Loss of micronutrients and soil organic matter is particularly problematic because they cannot be remedied by the use of conventional inorganic fertilizers and tend to reduce the efficiency of inorganic fertilizers in contributing to crop output (Lal, 2011; Marenya and Barrett, 2009; Vanlauwe et al., 2011). If the current rate of land degradation continues, more than half of Africa's cultivated agricultural area will be destroyed by 2050. To minimize the disastrous repercussions for populations' livelihoods, with the poorest residing in the most degraded areas, research has advised the implementation of an integrated land management approach. This technique entails restoring the soil by increasing organic matter, maintaining moisture and increasing the usage of inorganic fertilizers. This is the fundamental approach to increasing agricultural productivity in a sustainable manner.

Conclusion

The study investigated the impact of emerging issues in African agriculture, such as maize fall armyworm, aflatoxins in cereals, African swine fewer in pigs, and climate change issues in agriculture. This was accomplished by doing a scoping review using bibliometrics (Web of Science, CiteULike, and Science Direct) as well as a systematic review covering the years 2008–2021. The findings revealed that developing concerns have significant impacts on agricultural and food security in Africa, particularly among the poor. Furthermore, the results demonstrated that sustainable technologies had the potential to address rising difficulties in African agriculture. However a variety of efforts promoting the progress of creative and advanced technology might be implemented to develop frameworks for managing rising difficulties in African agriculture. African agriculture's production must be boosted by the implementation of innovative and modern technology.

Acknowledgements

We are grateful to the Forum for Agriculture Research in Africa (FARA) for its support during the period of the study.

CREDit Authorship Contribution Statement

Adeolu B. Ayanwale: conceived the project and supervised the work. **Fatunbi A. Oluwole:** contributed to the editing of the manuscript. **Ayodeji D. Kehinde:** investigated, analyzed the data and drafted the manuscript. **Buruchars Robin:** contributed to the editing of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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