FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

FEED THE FUTURE INNOVATION LAB FOR FOOD SAFETY (FSIL)

Food Safety Programs and Academic Evidence in Senegal

USAID FROM THE AMERICAN PEOPLE

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Food Safety Programs and Academic Evidence in Senegal

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Acronyms

CILSS	Comité Permanent Inter-États de la Lutte contre la Secheresse dans le Sahel (Permanent Interstate Committee for Drought Control in the Sahel)
DALY	Disability-Adjusted Life Year
ELISA	Enzyme-linked Immunosorbent Assay
FAO	Food and Agriculture Organization of the United Nations
GAFSP	Global Agriculture and Food Security Program
GFSP	Global Food Safety Partnership
IFDC	International Fertilizer Development Center
IL	Innovation Lab
PACA	Partnership for Aflatoxin Control in Africa
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development
WHO	World Health Organization

Executive Summary

Smallholder farmers and consumers in sub-Saharan Africa (SSA) face numerous biological- and chemical-based food safety threats. According to estimates from the World Health Organization (WHO), this region of the world faces the highest burden of foodborne illness per capita, with an estimated 137,000 deaths and 91 million acute illnesses per year (WHO, 2015). WHO also estimates that 70% of the disease burden is caused by bacterial contaminants (e.g., *Salmonella*, pathogenic *E. coli*), while parasites (e.g., pork tapeworm) contribute to 17% of the burden. The remainder of the burden arises from other hazards, including chemical hazards such as aflatoxins (mainly affecting cereals and grain legumes), pesticide residues, cyanide (affecting processed cassava), and dioxins (commonly found in dairy products, meat, fish, and shellfish). While African policymakers, donors, and the broader international development community have traditionally placed resources and emphasis on food production and food security, food safety is beginning to rise on the development agenda. This report contributes to this focus by documenting and analyzing the current landscape of projects and evidence about food safety threats in major food commodities in Senegal, including rice, maize, millet, groundnuts (peanuts), and fish.

The Global Food Safety Partnership database shows that international donors spent $383 million[1] to support 323 projects aiming to improve food safety throughout Africa between 2010 and 2017. The projects with the largest funds and presence in Senegal include the Aflasafe Technology Transfer and Commercialization and the Partnership for Aflatoxin Control in Africa II. Both are funded by the Bill & Melinda Gates Foundation. Other donors funding significant efforts to improve food safety in Senegal include the U.S. Agency for International Development and the European Commission.

The academic evidence on the burden of foodborne diseases in Senegal, and the effectiveness of approaches to reducing it, is sparse. Our review found no indicators of the burden of foodborne illnesses in the country, and there are few peer-reviewed publications measuring bacterial or parasitic contamination in rice, maize, millet, groundnuts, or fish in Senegal. There is evidence of contamination from aflatoxins, which are widespread in Senegal, although levels vary among crops, varieties, regions, seasons, post-harvest management practices, and storage locations (Diedhiou et al., 2011; Watson et al., 2015). We found only one study estimating the impacts of a scalable approach to reducing aflatoxin levels by improving smallholder production practices in Senegal (Bauchet et al., 2020). The authors found that providing hermetic (airtight) storage bags along with a suite of inputs including training on proper post-harvest practices, tarps, and low-cost moisture meters reduced aflatoxin levels in stored maize by approximately 30%. The combination of the other inputs without the hermetic storage bags, however, did not significantly affect aflatoxin levels.

Our review of the literature indicates that more research is required to (i) document the extent of contamination in foods produced and consumed in Senegal and in Africa, and (ii) rigorously

[1] All amounts preceded by a $ sign are in United States dollars (USD).

test the impact of scalable, integrated pre- and post-harvest strategies aiming to improve production practices and increase the safety of crops for food and feed. With much of the international development community's focus shifting towards food safety issues, funding for these approaches could then be dedicated to scaling up successful interventions and boosting populations' food safety and nutrition, together with smallholder farmers' income and consumption.

1. Problem Statement

Feeding a growing global population while at the same time providing safe and nutritious food is a challenging and complex problem. Food safety (defined as a concern with the risk of foodborne illness[2]) is gaining attention in the international development agenda as a critical component of food security (defined as access to sufficient, affordable, and nutritious foods). Foodborne illness can occur from ingestion of water or food contaminated with toxic bacteria, viruses, parasites, or chemical substances (Henson, 2003). Food can also be cross-contaminated by unsafe fluids, insects, preparation, and utensils used for consumption (Grace, 2015).

In a comprehensive report published in 2015, the World Health Organization (WHO) estimated that foodborne illness affects approximately 600 million people worldwide, with 420,000 deaths each year (WHO, 2015). Children aged five years and below are particularly vulnerable, with more than 125,000 deaths from foodborne illness annually. The continent of Africa faces the highest foodborne illness burden per capita, with an estimated 137,000 deaths and 91 million acute illnesses per year (WHO, 2015). The report estimated that in Africa alone, 22 diseases transmitted by contaminated foods caused by a mixture of viruses, bacteria, and chemicals impact the lives of African populations.

In Africa, bacterial and viral hazards are responsible for 70% of the foodborne disease burden; diarrheal disease has the highest mortality rate, with nine deaths per 100,000 people (WHO, 2015). Parasites contribute to 17% of the burden, with *Taenia solium* (pork tapeworm), *Ascaris* spp., protozoa *Cryptosporidium* spp., and *Toxoplasma gondii* being the most significant parasites in the region (WHO, 2015). Aflatoxins are the most pervasive chemical hazard on the continent, affecting mainly staple crops (cereals and grain legumes) (WHO, 2015).[3] Less common hazards include high levels of cyanide in insufficiently processed cassava and dioxins, which are industrial chemicals commonly found in dairy products, meat, fish, and shellfish (See Table 1 for a summary of the most prevalent pathogens in SSA).

Although the numbers cited above suggest an acute food safety issue, little is known about the sources of foodborne diseases in many developing countries, including those in SSA. Many of these countries do not monitor food safety and foodborne illness as closely as developed countries. This includes watching critical points of contamination in food supply chains and the cost and benefit of different interventions aimed at improving food safety. For example, Senegal does not currently regulate the maximum amount of aflatoxins allowed in staple and export crops, such as maize and groundnuts (Kébé, 2017).

The West African country of Senegal is home to nearly 16 million people, 77% of whom are engaged in agriculture as their main occupation (CIA World-Factbook, 2020). Groundnuts, rice,

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[2] According to the Australian institute of food safety, "food safety refers to handling, preparing and storing food in a way to best reduce the risk individuals becoming sick from foodborne illnesses" (https://www.foodsafety.com.au/resources/articles/what-is-food-safety).

[3] The total burden of aflatoxins is likely higher since the WHO report only considered impact on liver cancer due to the lack of surveillance and health indicators for each country.

maize, and millet are major staple crops produced and consumed in Senegal, mainly by smallholder farm households using traditional production, harvest, and post-harvest methods. Fish and poultry are important animal products for the Senegalese population. Furthermore, Senegal is one of the U.S. Government's Feed the Future initiative's focus countries. The United States Agency for International Development (USAID) identifies Senegal as one of the most stable and promising nations in West Africa for economic success and development. Feed the Future programs seek to open new doors of agricultural expansion and implement nutritional programs to combat malnutrition and reduce poverty rates. These efforts aid in promoting trade and access to markets to support local smallholder and medium-sized farmers and businesses (www.feedthefuture.gov/country/senegal/).

This report has two main objectives: (i) to provide an overview of ongoing projects aiming to increase food safety in Senegal and, (ii) to review the existing academic research focused on improving the safety of rice, maize, millet, groundnuts, and fish produced and consumed in Senegal. These commodities were identified as priorities by USAID and the Senegalese government for the Feed the Future initiative and are vital products for Senegalese consumers.

2. Review of the landscape of projects, interventions, and approaches currently taking place in Senegal to improve food safety

The Global Food Safety Partnership (GFSP, 2019) is a public-private initiative that supports global cooperation for improving food safety capacity in low- and middle-income countries. The GFSP has outlined the food safety projects that have been or are currently being implemented in West Africa. It reports that current investments in food safety are mainly oriented toward export commodities. Less than 5% of investments are directed to investigate and combat specific microbiological hazards for local consumers in SSA. In addition, the lack of information on the impact, cost, and effectiveness of food safety interventions may affect the willingness of governments and smallholder farmers to invest in food safety.

The GFSP gathered data from 518 projects and activities in SSA funded by 31 donor organizations between 2010 and 2017. The World Bank Group, the European Commission, the United States, the Food and Agriculture Organization of the United Nations (FAO), and WHO have been the most active financers of food safety projects in SSA. The largest investments have come from the World Bank Group ($96 million), the European Commission ($76 million), and the United States ($52 million). These numbers apply to SSA as a whole and are not disaggregated by country. Senegal-specific ongoing projects targeting food safety with the largest funds and presence include the Aflasafe Technology Transfer and Commercialization initiative ($10 million) and the Partnership for Aflatoxin Control in Africa ($4 million), both funded by the Bill & Melinda Gates Foundation. Other agriculture-focused projects in Senegal are supported by the Millennium Challenge Corporation (approximately $168 million), USAID (approximately $181 million), and the African Development Fund (approximately $4 million) (USAID Foreign Aid Explorer, 2020). More details on these projects and other initiatives currently under execution in Senegal can be found below.[4] Projects, funders, and amounts allocated (when available) are summarized in Table 2.

2.1. United States Agency for International Development – Projects other than Innovation Labs

The Feed the Future Senegal Country Plan identifies three objectives to achieve the goal of sustainably reducing hunger, malnutrition, and poverty in the zone of influence for the period 2018-2022. Those three objectives are (1) inclusive and sustainable agricultural-led economic growth, (2) strengthened resilience among people and systems, and (3) a well-nourished population, especially women and children (www.feedthefuture.gov/resource/global-food-security-strategy-gfss-senegal-country-plan/). The Feed the Future plan is expected to be implemented via five components: (1) value chain services that seek to increase income and employability, (2) nutrition services that aim to improve the link between health and agriculture, (3) sustainable ecosystem and fisheries management services that seek to face the threats to fisheries, (4) entrepreneurship and vocational development services that work to improve youth inclusion in the economy, and (5) policy system services that aim to help the

[4] Additional information on other countries and past projects can be found at https://www.gfsp.org/resources.

government identify the main priorities in the country. Within these components, USAID and its mission in Senegal are supporting the following programs.

2.1.1. Senegal Dekkal Geej

Funded by USAID and implemented by Winrock International, the Senegal Dekkal Geej project aims to build sustainable fisheries in Senegal. It works with local and national governments, civil society actors, and the private sector and focuses on improving fisheries management practices. The project spans from 2019-2024 and over the five years will build on previous USAID interventions using six strategic approaches: advocacy, decision-making, co-management, behavior change, livelihoods, and policy. More information is available at www.winrock.org/wp-content/uploads/2019/06/20200103-FtF-Senegal-Dekkal-Geej-Handout.pdf.

2.1.2. Feed the Future Senegal Cultivating Nutrition (Kawolor)

This project aims to increase consumption and commercialization of healthy and nutritious foods by promoting diverse diets, using a model that trains and supports local institutions and leaders to spearhead the development of their own communities. The main focus is on women of reproductive age and children under two years of age. The project's implementation period runs from 2017 to 2022.

2.1.3. Feed the Future Senegal Commercializing Horticulture (Nafoore Warsaaji)

This project's purpose is to help small commercial horticulturalists, including those already being supported under existing Feed the Future projects, to expand their commercial activities and integrate farmers into existing horticulture value chains. The focus is to engage these participants in increasingly lucrative and structured business deals with private sector partners, including input suppliers, microfinance institutions, banks, insurance companies, off-takers, and end market buyers. The project's implementation period runs from 2020 to 2023.

2.1.4. Feed the Future Senegal Youth in Agriculture

This project supports the institutionalization of youth development and vocational training systems that boost entrepreneurship and employment opportunities for youth, with the main focus on agricultural value chains and markets. More information is available at www.cired.vt.edu/programs/feed-the-future-senegal-youth-in-agriculture.html.

2.1.5. Business Drivers for Food Safety

The Business Drivers for Food Safety project aims to strengthen the capacities of micro, small, and medium-sized food enterprises in the effort to reduce malnutrition, pre-consumer food loss, and overall hunger. Recent efforts in Senegal included a Food Safety Situational Analysis (from March–July 2020) and assessment of conditions that affect the ability of supply-chain actors — fisherfolk, fish processors, fishmongers, vendors, technology suppliers, and transporters — to adopt food safety practices. More information is available at https://www.agrilinks.org/post/food-safety-situational-analysis-artisanal-seafood-sector-senegal-technical-learning-note.

2.1.6. Other USAID engagements

USAID is also supporting projects implemented by partnerships and multilateral financing mechanisms including the Global Agriculture and Food Security Program (GAFSP) and the International Fertilizer Development Center (IFDC). GAFSP seeks to support farmers through warehouse financing, a lending technique that provides farmers in developing nations with loans, using their crops as collateral (www.ifc.org/wps/wcm/connect/1499606d-d172-4b2d-a30c-8a55fb2b11ff/BICIS.pdf?MOD=AJPERES&CVID=kqCBPAH). IFDC seeks to improve the agricultural sector in Senegal by encouraging the adoption of technologies that improve soil fertility to raise yields for smallholder farmers as well as provide estimates of fertilizer markets and consumption (www.ifdcorg.files.wordpress.com/2016/05/senegal-fertilizer-assessment.pdf). Both programs could have food safety implications if widely adopted, however food safety is not a significant priority for either GAFSP or IFDC.

2.2 USAID Feed the Future Innovation Labs

USAID's Feed the Future Innovation Labs draw on experts from leading U.S. and developing country research institutions to find solutions to the primary challenges in agriculture and food security. The following initiatives include all the Feed the Future Innovation Labs with recent activities related to food safety in Senegal. Other Innovation Labs working in Senegal but with no direct food safety objectives include the Innovation Labs for Food Security Policy, Legume Systems Research, Peanuts, Sorghum and Millet, and Sustainable Intensification. Further information is provided in Table 3.

2.2.1. Feed the Future Innovation Lab for Food Processing and Post-Harvest Handling

The Food Processing and Post-Harvest Handling Innovation Lab began in 2014 with a primary focus on analyzing post-harvest loss reduction, and value-added processing of cereals and grain legumes in Senegal and Kenya. Its goal is to increase access to safe and nutritious foods along the value chain by (i) improving the drying and storage capacity of smallholder farmers and (ii) expanding market opportunities through diversified products to address quality and nutritional needs. The project attempts to improve the drying and storage capacity by improving technology, public-private partnerships, and market availability of high-quality grains and legumes. The plan for expanding market opportunities is to enhance the nutrition of locally available commodities, accelerate food and nutrition security for consumers, expand markets for producers, and improve economic growth in the agricultural sector. More information is available at www.ag.purdue.edu/food-processing-innovation-lab/.
Lead University: Purdue University. Director: Jacob Ricker-Gilbert, jrickerg@purdue.edu

2.2.2. Feed the Future Innovation Lab for Food Safety

The Feed the Future Innovation Lab for Food Safety aims to enhance global agricultural sustainability and resilience, as well as food security. The lab's applied research leverages collective expertise in food safety, food production, nutrition, and international development. Its work can strengthen nutritional outlooks and well-being in developing nations by (i) increasing awareness of food safety issues and impacts, (ii) building capacity to conduct research on local food safety issues, (iii) developing public-private partnerships, policies, and networks for engagement of results, and (iv) translating research findings into training and

guidelines for commercialized products. More information is available at www.ag.purdue.edu/food-safety-innovation-lab/
Lead University: Purdue University. Director: Haley Oliver, hfoliver@purdue.edu

2.3 The Alliance for Accelerating Excellence in Science in Africa

The Alliance for Accelerating Excellence in Science in Africa (www.aasciences.africa/aesa) is a platform of the African Academy of Sciences and the New Partnership for Africa's Development to support research in health in Africa. It is currently implementing the project "Afrique One-ASPIRE: Foodborne diseases and nutritional illness TTP (4)" (www.afriqueoneaspire.org/thematics/ttp-4-food-borne/). The project started in 2016 and ends in 2020. This collaboration is currently implementing a project that will address the links between foodborne illness and human health. This study also aims to show the effectiveness of risk-based intervention strategies to reduce the disease burden associated with contaminated foods, specifically microbial contamination in meat and dairy products. The executing institution in Senegal is the École Inter-États des Sciences et Médecine Vétérinaires de Dakar. The alliance's contribution to this project is $775,293.49.

2.4 The Bill & Melinda Gates Foundation

The Bill & Melinda Gates Foundation is currently funding two separate projects active in Senegal with a focus on aflatoxin contamination in maize and groundnuts: the Partnership for Aflatoxin Control in Africa and the Aflasafe Technology Transfer and Commercialization initiative. They are described in more detail in the following sections. In addition to these projects, the foundation supports several food safety-related research projects throughout Africa in collaboration with the U.K. Department for International Development. These include interventions to address foodborne disease risk among young children in Mozambique and Kenya, ensuring safety and quality of milk in the dairy value chain of Ethiopia, assessing the risk from nontyphoidal *Salmonella*, diarrheagenic *Escherichia* coli, and *Campylobacter* spp. in raw beef and dairy in Ethiopia, and estimating the burden of foodborne disease in Tanzania, Ethiopia, Mozambique, and Nigeria (www.anh-academy.org/dfid-bmgf-agriculture-nutrition-research-investments). The foundation's contribution to these projects is $12,488,278.

2.4.1. Partnership for Aflatoxin Control in Africa

The Partnership for Aflatoxin Control in Africa (PACA) aims to generate evidence for the prevalence of aflatoxins, improve knowledge diffusion of strategies to combat aflatoxin contamination by engaging the public and private sector, and increase the aflatoxin-free food supply. The project is implemented in six pilot countries in Africa (Gambia, Malawi, Nigeria, Senegal, Uganda, and Tanzania). Its implementation period is 2016-2020, with a total budget of $4,000,000.

PACA's current priorities include creating health indicators to show the burden of diseases due to aflatoxins (e.g., indicators on liver cancer). PACA is also carrying out surveys in every pilot country to learn more about the current state of aflatoxin contamination. It also funds ongoing work on farmers' awareness of aflatoxin contamination and the use of Aflasafe, a biocontrol agent used during the growing season that controls aflatoxin levels in the field (www.aflasafe.com/aflasafe/).

PACA has specifically been involved with Senegalese efforts to control aflatoxins, contributing to the Senegalese National Plan against Aflatoxins (Plan d'action de lutte contre les aflatoxines au Sénégal*)*, published in 2016. The PACA country officer in Senegal is part of the "National Codex Alimentarius Committee (Comité national du Codex Alimentarius; CNCA),"[5] which is planning to launch a document on good production practices for farmers and to evaluate aflatoxin contamination levels along the production chain. The National Codex Committee is also discussing the adoption of official maximum allowable levels of aflatoxins (likely 10-20 parts per billion) in foods produced in Senegal; no legal limit currently exists.

PACA-Senegal currently follows aflatoxin contamination in groundnuts, rice, and maize. Although the National Codex Committee is very well informed of the aflatoxin problem, they have never addressed other contaminants such as *Escherichia coli* and coliforms. However, the Comité National de L'alimentation, a separate entity in the Senegalese government, has discussed these bacterial contaminants.

Other food safety issues identified by PACA that need to be addressed in Senegal are the burden of aflatoxins on animal health, the existence of contaminated products that result in local market sales after an initial rejection by the main commodity purchasers, and the lack of public information regarding food safety concerns. Due to the lack of public information, PACA scientists tested 2,500 samples of aflatoxin-contaminated groundnuts on farms and in markets across the country in collaboration with the Agence Nationale de Conseil Agricole et Rural, and they are currently working to disseminate these results. However, preliminary results have shown high levels of contamination (above 1,000 ppb) in shelled groundnuts, tourteaux d'arachide (a by-product of oil processing by artisanal oil processors which is often used to feed animals), and peanut paste (a staple of Senegalese cuisine).

2.4.2. Aflasafe Technology Transfer and Commercialization

This is a $10 million project implemented by the International Institute of Tropical Agriculture through its business incubation platform, with additional funding from USAID and the CGIAR Research Program on Agriculture for Nutrition and Health. This initiative seeks to identify partnerships with public entities and private companies to ensure Aflasafe products reach millions of farmers in Africa. These partnerships will also register Aflasafe in the target countries and aim to ensure availability and access through agreements with manufacturers and distributors, as well as create market demand for aflatoxin-safe products. This is a continent-wide project from 2016 to 2020 executed in Burkina Faso, Gambia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Senegal, Uganda, Tanzania, and Zambia. More information on the project available at www.aflasafe.com/wp-content/uploads/pdf/ATTC-brochure.pdf.

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[5] The Codex alimentarius ("Food Code") is a joint FAO-WHO program created in 1963 that maintains a code of standards, guidelines, and best practices to promote food safety worldwide.

2.5 European Commission

The European Commission is currently executing a project titled “Fit for Market - Strengthening competitiveness and sustainability of the African, Caribbean and Pacific region.” The project is focused on pesticide use in fruits and vegetables and seeks to allow stakeholder access to international and domestic fruit and vegetable markets following the sanitary and phytosanitary measures and agreements and market requirements. This project has a presence in Senegal and 24 other countries in Africa and Oceania. The project’s implementation period runs from 2016 to 2020 with a total budget of $11,063,225.

2.6 Food and Agriculture Organization of the United Nations

The Food and Agriculture Organization of the United Nations funded a project from 2015 to 2019 which aimed to improve the use and management of pesticides and pesticide-associated materials in member states of the Comité Permanent Inter-États de la Lutte contre la Secheresse dans le Sahel (CILSS; Permanent Interstate Committee for Drought Control in the Sahel). The activities implemented include disposal of existing stocks of obsolete pesticides and associated wastes, management of empty pesticide containers in CILSS countries, and promotion of alternatives to chemical pesticides. The project included all members of the CILSS committee: Burkina Faso, Cabo Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, and Senegal.

2.7 World Health Organization

The World Health Organization (WHO) is currently executing two projects or studies in Senegal and supports the Codex Alimentarius.

2.7.1. Research studies

The first project conducted by WHO is a multi-country study to investigate multidrug-resistant extended-spectrum and AmpC *a*-lactamase-producing *E. coli* and *Salmonella enterica* in humans, food animals, meat products, and agricultural environments. This study started in 2016 and is expected to be conducted in 14 SSA countries in addition to Senegal. Second, WHO is conducting research on enteric pathogens from human, animal, and food sources including their potential for antimicrobial resistance. This study is being conducted in Senegal and 15 other SSA countries.

2.7.2. Codex Alimentarius support

In addition to these studies, the FAO and WHO recently finished implementing the joint project “Codex Trust Fund Support of Senegal,” which sought to improve the understanding and awareness of Codex Alimentarius standards, boost compliance with these standards, and increase the competitiveness of food items in local, regional, and international markets. This project started in 2016 and ended in 2019. The total budget for this project was $232,350.

2.8 Government of Luxembourg

The project funded by this donor is called “Crisis management and food safety with implementation in Senegal and Burkina Faso,” a follow-up project to the Strengthen Food Safety Surveillance program, which was conducted between 2015 and 2017. Its main goal is to help countries strengthen their national food safety systems and improve their expertise in early responses to food crises. Similar to the WHO and FAO projects described above, the Strengthen Food Safety Surveillance program also aimed to support the Codex Alimentarius. The key take-aways from this project include the necessity of engaging stakeholders, the importance of consumer associations in lobbying authorities, and a need for greater awareness for decision-makers of the Codex on food safety issues (www.who.int/foodsafety/publications/CTFcountrysupport/en/index3.html; www.who.int/foodsafety/publications/Senegal-PS.pdf). The new phase of this initiative started in 2018 and ended in 2020 with an estimated budget of $1,173,708.85.

3. Review of academic literature on bacterial contamination and aflatoxins in maize, millet, rice, groundnuts, and fish

This section synthesizes the academic literature identified through a review of food safety research associated with the Senegalese commodities of interest identified by USAID (www.feedthefuture.gov/country/senegal/), which include rice, maize, millet, groundnuts, and fish. It includes the major food safety hazards identified by WHO (2015) in Africa: nontyphoidal *Salmonella enterica;* enteropathogenic *E. coli;* enterotoxigenic *E. coli; Campylobacter spp.;* coliforms; norovirus; the parasites *Taenia solium, Ascaris spp.*, *Cryptosporidium spp*., and *Toxoplasma gondii;* and cyanide, dioxins, and aflatoxins.

3.1 Bacterial and viral contamination

3.1.1. Extent and type of contamination in Africa

Bacteria and viruses are microscopic organisms that live in diverse environments such as soil, water, and the human gut (Grace, 2015). In a comprehensive report published in 2015, WHO estimated that in Africa 22 illnesses contracted by consuming contaminated food resulted in 10.8 million Disability-Adjusted Life Years (DALYs) in 2010 in children aged less than 5 years and 14.3 million DALYs in the population aged more than 5 years. Almost 95% of the foodborne illness burden was associated with diarrheal diseases causing 9,830 illnesses and 9 deaths per 100,000 persons in the year 2010 (WHO, 2015). The primary pathogens of concern were *Campylobacter* spp. (2,221 illnesses per 100,000 people annually), norovirus (1,749 illnesses per 100,000 people annually), *E. coli* (1,436 illnesses per 100,000 people annually), and nontyphoidal *Salmonella enterica* (896 illnesses per 100,000 people annually). The same report also estimated that the main source of contamination for *Campylobacter* spp. and nontyphoidal *Salmonella enterica* is mishandled and undercooked food, while consumption of contaminated water is the predominant source for *E. coli*, and human-to-human physical contact for norovirus. Table 4 details the estimated median values and confidence intervals for all the possible exposure pathways.

Bacterial contamination can occur during crop production when pathogens are transferred from contaminated water to crops via irrigation, through the application of inadequately composted animal manure or biosolids as fertilizer, and due to proximity to animal production facilities (Suslow et al., 2003). Livestock are known reservoirs for many pathogens, including *E. coli*, *Salmonella* spp., and *Campylobacter* spp.; therefore, crops grown and harvested near livestock are likely to become contaminated with common pathogens of concern. It is also possible for crops to become contaminated by farm workers without access to latrines or handwashing facilities during harvest and even from water used to spray fungicides on plants and crops. Contamination during processing can occur when food is washed with contaminated water and contact with contaminated chill tanks, sprays, or shipping ice (Lynch et al., 2009). During preparation, contamination occurs when food is prepared with unclean instruments, hands, or surfaces or using inappropriate cooking methods or temperatures; or when a person with poor hygiene spreads the pathogens (Lynch et al., 2009).

Strategies to control bacterial contamination in crops include taking action during the growing, processing, transportation, storage, and preparation of food. Lynch et al. (2009) highlights the importance of water that is utilized to apply pesticides and for post-harvest processing as well as the necessity to control water runoff and protect groundwater sources that are commonly used for application during growing and for washing crops after harvest. Other critical recommendations include protection from fecal contamination, from domesticated and wild animals (including animal manure) as well as from humans (Furtula et al., 2012; Verhougstraete et al., 2015), and management of cold storage throughout the supply chain (Badia-Melis et al., 2018; Kim et al., 2015). Recommendations to avoid bacterial contamination of manure include waiting 60 to 100 days between manure application to soil and planting, determining the optimal conditions for composting manure for the lethality of bacteria and parasites, identifying contamination on surfaces used for harvest and post-harvest processing, and the presence of bacteria in reusable containers used for field operations and storage (Suslow et al., 2003).

Additionally, soil characteristics, climate, and microflora conditions determine the survival of bacteria in the soils. Xing et al. (2019) reports that higher pH levels in soils are the major abiotic drivers of *E. coli* survival. Mallon et al. (2015) reports that a higher presence of microbes in the soil creates more difficulty for additional microbial invasions due to competitive inhibition. Climate conditions have an effect on microbial survival, as droughts typically have negative effects on survival, rainfall can lead to additional dispersion of microorganisms, and rising global temperatures are expected to increase the presence of certain soil microbes (Hellberg & Chu, 2016).

Our review did not reveal any existing reports providing disaggregated estimates on the burden of foodborne illness for each African country, how widespread these illnesses are, or studies assessing how aware Africans are about microbial pathogens. In addition, to the best of our knowledge, there is no evidence on the effectiveness of practices known to reduce the risk of bacterial contamination or evaluating the survival of pathogenic microorganisms, as described above, in the African context and particularly among smallholder farmers who provide most of the food supply.

3.1.2. Limited evidence on contamination in seafood in Senegal

One study reported levels of microbial contamination in seafood products in Senegal. Diop et al. (2019) reported that lactic acid bacteria, H_2S-producing *Enterobacteriaceae,* and *Staphylococci* are the predominant microorganisms identified in *Arius heudelottii* fish after fermentation at 25-30°C. Enumeration of these microorganisms occurred after the addition of salt and millet (common fermentation sources in Senegal) to the fish. The authors also reported that H_2S-producing bacteria were the most abundant after 24-hour fermentation in the control groups; however, the authors also found that fermentation in saltwater with NaCl (80%) resulted in growth inhibition of H_2S-producing *Enterobacteriaceae*. Fish fermented with malted millet (15%) also weakened the growth of H_2S-producing *Enterobacteriaceae, Staphylococci*, and spore-forming bacteria. Additionally, the academic literature search did result in a single study analyzing *Salmonella* spp. contamination associated with water. Ndiaye et al. (2011) reported that lettuce produced on two urban agricultural sites in Senegal was more contaminated when irrigated with shallow groundwater than when irrigated with wastewater or well water.

3.1.3. Contamination in crops in Senegal

Currently, most research has been conducted to evaluate the burden of foodborne disease on a few important crops and food items in Senegal, such as *Vibrio* spp. in various seafood products (Coly et al., 2013), *Salmonella* spp. in beef and poultry (Pouillot et al., 2012; Stevens et al., 2006), and the general microbiological quality of raw milk (Breurec et al., 2010). However, there are few studies reporting the bacterial contamination of the commodities of interest identified through USAID (rice, maize, millet, groundnuts, and fish). To the best of our knowledge, there are no prior studies evaluating *Salmonella* spp*.* contamination on rice, maize, millet, and groundnuts, nor were there any reports of norovirus incidence associated with rice, maize, millet, groundnuts, or fish.

Additionally, there are few studies associated with microbial contamination in poultry production in Senegal. Vounba et al. (2019) reported *Escherichia coli* prevalence and antimicrobial resistance in chicken farms in the Dakar region. *Campylobacter* spp. and *Salmonella* spp. were linked to chicken meals (Pouillot et al., 2012), chicken neck-skins (Garin et al., 2012), chicken carcasses (Bada-Alambedji et al., 2006), broiler-chicken flocks (Cardinale et al., 2004), and ready-to-eat poultry dishes sold in street stalls (Cardinale et al., 2005). Rates of contamination ranged from 10 to 97% of samples, with many studies reporting rates higher than 50%. Since chicken is not deemed a focus commodity by USAID in Senegal, we provide no further details in this report.

3.2. Parasitic contamination

Parasites are defined as organisms living in or on other organisms without benefiting the host (FAO/WHO, 2014). Parasites can be transmitted to humans and animals via fresh or processed foods contaminated with animal feces or by people handling food with poor hygiene; raw and under-cooked or poorly processed meat and offal from domesticated animals are of high concern for parasitic contamination (FAO/WHO, 2014). Similar to research on bacterial contamination, there are no disaggregated estimates on how widespread these organisms are across Africa, or to what degree populations of African countries are aware of parasites and the likelihood of foodborne illness. Likewise, there are no published documents about the level of parasitic contamination on crops or fish in Senegal. Common practices to control crop contamination with parasites are similar to those described in the bacterial contamination section (Suslow et al., 2003).

A WHO report (WHO, 2015) noted that *Toxoplasma gondii* is the most commonly reported parasite associated with foodborne transmission worldwide. The predominant sources of contamination for *T. gondii* in Africa are food, soil, and water (Table 4), but we found no studies directly measuring the prevalence of *T. gondii* in foods in Senegal. The limited literature discussing contamination from *T. gondii* focuses on levels in animals (e.g., dogs, rodents) and humans, without direct links to contamination from food consumption (Brouat et al., 2018; Davoust et al., 2014; Galal et al., 2019; A. R. Kamga-Waladjo et al., 2009, 2009; K. Kamga-

Waladjo et al., 2013; A. Ndiaye et al., 2013; Odeniran et al., 2020; Pappas et al., 2009; Tonouhewa et al., 2017).

WHO has also highlighted the importance of parasites *Taenia solium* and *Ascaris* spp. and the protozoa *Cryptosporidium* spp. in foodborne illness (WHO, 2015). The academic literature discussing these in Senegal focused primarily on human cases using patients in laboratories and hospitals, as well as evaluating surface water for parasitic contamination, without explicit connections to food sources or food systems. For example, *Cryptosporidium* spp. affected an estimated 4.53 to 6.13% of children in Senegal, with the variance in estimates attributed to the methodologies used for testing, which included both the Ziehl-Neelson and ELISA methods (Faye et al., 2013).

3.3 Chemical contamination

Common chemical agents contaminating foods include aflatoxins, cyanide, and dioxins. Of these, aflatoxins are the most prevalent and best recognized threat to food safety throughout the African continent.

3.3.1. Aflatoxins in Senegal and Africa

Aflatoxins are carcinogenic mycotoxins produced by the fungi of the *Aspergillus* family, notably *Aspergillus flavus*. They are found in soils, from which they contaminate crops, including maize (corn), millet, sorghum, groundnuts, cassava, and cotton seeds, as well as animal products, including meat, eggs, poultry, and milk (Coppock et al., 2018; Eaton & Groopman, 2013; Wogan, 1966). Some crops, such as maize and groundnuts, are more likely to be contaminated by aflatoxins, resulting in chronic exposure for many populations. Aflatoxins are invisible, odorless, and tasteless, making them particularly difficult to control (Lewis, 2004; National Toxicology Program, 2016, 2019). Aflatoxins cause liver cancer, growth retardation, and in more serious cases, hemorrhaging, edema, and death (Xu et al., 2018; Liu and Wu, 2010; Shephard, 2008; Wild & Gong, 2010).

Although concern about aflatoxins has risen in the international development agenda in the last few years, there remain few academic papers on aflatoxins in Senegal. Our review found studies measuring aflatoxin contamination levels in rice, maize, groundnuts, and sesame. Watson et al. (2015) found high levels of aflatoxins in both groundnut samples and human adult blood using aflatoxins-albumin adducts (AF-alb). In three regions of Senegal, 28-80% of samples had detectable aflatoxin levels ranging from 6.5 to 50 ppb.[6] The study also recorded a pronounced variation of aflatoxin contamination by both region and season (Watson et al., 2015). It has also been reported that aflatoxin contamination significantly varies by storage location, variety, shelling method, and agroecological zone (Diedhiou et al., 2011). Two laboratory studies tested the resistance of various groundnut varieties to aflatoxin contamination (Dieme et al., 2018; Clavel et al., 2013). Dieme et al. (2018) reported that there are genotypes that are less prone to aflatoxin contamination; however, these conclusions are laboratory-based and have yet to be tested in the field. Additionally, very early maturing

[6] The threshold for human consumption is 4 ppb in the European Union and 15 ppb in the United States.

varieties that are ready for harvest in 80 days may also be less susceptible to aflatoxin contamination (Clavel et al., 2013). One study found high aflatoxin levels in peanut oil and food prepared by small-scale production plants in the Kaolack and Diourbel regions of Senegal, with the presence of aflatoxin B1 in 85% of the samples and an average of 40 ppb (Diop et al., 2000). Higher contamination levels were also found in samples infested by millipedes (5,400 ppb), termites (3,964 ppb), and in molded (1,964 ppb) and discolored (731 ppb) samples (Kane et al., 2006) as well as in immature damaged kernels and kernels without seed coats (Diedhiou et al., 2011).

Bauchet et al. (2020) found that Senegalese households who were educated on aflatoxin contamination and prevention and provided with a hygrometer (acting as a low-cost moisture meter [Tubbs et al., 2017]), a plastic sheet, and a hermetic bag for storage had statistically significantly lower levels of aflatoxins in stored maize. The combination of inputs reduced contamination by about 30% compared to a randomly selected control group that received no inputs. A recent study found that the technology Aflasafe SN01 is effective in reducing aflatoxin contamination during planting, with carryover effects during harvest and after storage (Senghor et al., 2019). These results were found through a longitudinal study, evaluating aflatoxin contamination of groundnuts by testing 72 fields in 2010, 80 in 2011, 76 in 2012, 120 in 2013, and 188 in 2014. Table 5 shows additional information on the aflatoxin literature in Senegal.

Evidence exists from other SSA countries on the effectiveness of approaches to combat aflatoxin contamination in common crops. Magnan et al. (2019) found that providing smallholder farmers in Ghana with a plastic tarp for drying groundnuts reduced aflatoxin levels by 31%. More recently, Pretari et al. (2019) compared the effectiveness of training on aflatoxins and their prevention, using tarps and an option to pay for a mobile drying service in Kenya. They found that training and tarps caused the largest drop in aflatoxin levels (over 50%). Turner et al. (2005) studied the role of training, drying mats, natural-fiber bags, wooden pallets, and insecticide usage in reducing aflatoxin levels in groundnuts in Guinea. The authors reported a drop in mean aflatoxin-albumin concentration in villages that received the package of inputs; however, they also cautioned that differences in the location of houses and agricultural practices between villages may have had an effect on the variation of the results, so their intervention may not have had any substantial effect.

3.3.2. Other chemical toxins in Senegal

Other chemical toxins with presence in Africa include cyanide, a chemical found in cassava that can lead to paralysis and has a 20% mortality rate. Cassava is particularly well-suited to Senegal because it can grow in terrain with erratic rainfall and infertile soil, it is inexpensive, and it can tolerate drought periods (Panghal et al., 2019). The review of academic literature on cyanide contamination in Senegal showed two studies of cassava in Senegal. Diallo et al. (2013) described how cassava consumption has been increasing in Senegal due to government efforts to intensify the production in the country for food security purposes. It focuses on describing the plant, its uses in Senegal, and its chemical components (both beneficial and toxic); the paper does not provide estimates of the extent of cassava-borne illnesses in Senegal.

Guédé et al. (2013) analyzed fresh and processed samples of four cassava varieties in Senegal. They found that cyanide levels varied by variety, between 104 and 270 mg HCN/kg of fresh material. In processed products, levels of contamination dropped by more than 80%, leading to the conclusion that processing "may be effective to reduce the cyanide content in cassava root down to a tolerable level (< 50 mg/kg)" (p. 225).

Processing methods could include simple wetting methods, which have been shown to reduce cyanide levels in cassava flour three- to six-fold in Mozambique (Nhassico et al., 2008). Processing may also greatly reduce the cyanide levels found in cassava leaves, which are often consumed in West Africa and are rich in proteins, minerals, and vitamins (Latif & Müller, 2015) but contain 5 to 20 times the cyanide levels found in roots (Bokanga, 1994).

Beyond cyanide, the evidence of food contamination by other chemical toxins is rare. We found only one study of the extent of contamination by dioxins in Senegal. Pesticide Action Network Africa (2005) analyzed eggs from free-range chickens roaming near a dump site in Dakar and found levels of dioxins more than ten times than those allowed by the European Union and 2.5 times greater than those allowed in the United States. The sampling location, however, implies that extrapolating these results to other foods or parts of Senegal must be done with caution.

4. Summary, conclusions, and opportunities for future work

Section 2 summarized ongoing projects by the U.S. government and other donors in Senegal related to the broad topic of food safety. While there are many projects and initiatives attempting to improve agricultural production and nutrition in Senegal, investments in improving food safety for the Senegalese (and African) population has lagged behind. Aflatoxins are the most recognized food safety threat in Senegal, yet there are only two large-scale initiatives addressing aflatoxin contamination in this country. These projects are the Partnership for Aflatoxin Control in Africa and the Aflasafe Technology Transfer and Commercialization initiative. The former program is working on aflatoxin regulation in Senegal and the latter is supporting the production and promotion of Aflasafe SN01, a biological control that has been shown to successfully reduce total aflatoxin contamination of treated fields and crops in Senegal (Senghor et al., 2019). However, food safety issues are rising on the development agenda. The European Commission, FAO, and WHO have projects in Senegal involving pesticide control in fruits and vegetables as well as initiatives to conduct research on bacterial contamination of crops, food animals, and meat products as well as antimicrobial resistance in humans and animals.

In the academic realm, there is a dearth of systematic evidence on the burden of foodborne disease, as can be evidenced in Section 3, particularly in crops. There are few peer-reviewed articles assessing bacterial contamination in fish and few studies analyzing aflatoxin contamination for each crop of interest. We found no studies that examined parasitic contamination in rice, maize, millet, groundnuts, or fish. This lack of evidence portrays the unknown burden of these hazards for local consumers. Foods contaminated with bacteria and parasites can create a vicious cycle of diarrhea and malnutrition, and they pose additional health risks for vulnerable populations, including children, the elderly, and immunocompromised individuals.

Bauchet et al. examined the cost-effectiveness of methods to prevent aflatoxin contamination in maize among smallholder farmers living in Senegal (Bauchet et al., 2020). It found that the combination of training on aflatoxins and post-harvest practices to prevent them, a moisture meter, a tarp, and a hermetic storage solution led to a 30% decrease in aflatoxin contamination. Aflasafe, a natural product that controls aflatoxins during the planting season, is a successful preventive (Bandyopadhyay et al., 2019; Senghor et al., 2019). A few other studies have tackled the challenge of helping smallholder farmers prevent or reduce aflatoxin contamination in crops in other African countries (Magnan et al., 2019; Pretari et al., 2019; Turner et al., 2005). Collectively, these studies suggest that simple and relatively inexpensive inputs are effective methods that significantly decrease aflatoxin levels in maize and groundnuts.

The lack of research on more commodities and different contaminants is particularly significant because a small number of hazards that have been minimally researched are responsible for the majority of the human health burden in SSA. Additionally, the complexity and diversity of the landscape in the continent require an understanding of food safety at both the national and local levels (Global Food Safety Partnership, 2019). The results in this landscape analysis underscore the need to test the impact of integrated strategies that include both pre-harvest and post-harvest interventions aiming to reduce bacterial contamination and aflatoxins in crops for food and feed, improve production practices, and boost smallholder farmers' income, consumption, and nutrition. Further research is also needed on consumer preferences for foods with low contamination levels, possibly at a price premium.

Similarly, the lack of evidence on the cost-benefit ratio of specific interventions to control foodborne diseases inhibits efforts aimed to improve food safety standards. Increasing awareness of these biological and chemical hazards among consumers could allow them to understand the health burden associated with microbial and chemical contamination. This could catalyze their interest in demanding and paying a premium for safer food, ultimately enhancing the willingness of producers to minimize the contamination risk of their foods through improved planting, drying, and storing practices.

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Table 1. Summary of the most prevalent pathogens in sub-Saharan Africa.

Pathogen	Definition	Sources of contamination	Commodities affected	Killed by cooking?	Other characteristics
Bacteria					
Nontyphoidal *Salmonella enterica*	Bacteria that can survive several weeks in a dry environment and several months in water	People can be infected via the stool of infected people or contact with animals	Meats, eggs, vegetables, or dry foods such as spices, chocolate, and nuts	Yes	Salmonellosis can cause fever, abdominal pain, diarrhea, nausea, and sometimes vomiting
Escherichia coli (*E. coli*)	Bacteria commonly found in the lower intestine of warm-blooded organisms	Consumption of contaminated foods	Raw or undercooked ground meat products, raw milk, and contaminated raw vegetables and sprouts	Yes	It is destroyed by cooking of foods until all parts reach a temperature of 70 °C or higher
Campylobacter spp.	Most common bacterial cause of human gastroenteritis in the world	Undercooked meat, meat products, raw or contaminated milk. Contaminated water or ice. Carcasses or meat are contaminated from feces during slaughtering	Food animals such as poultry, cattle, pigs, sheep, and ostriches; and in pets, including cats and dogs. The bacteria have also been found in shellfish	Yes	Symptoms of *Campylobacter* infections include diarrhea (frequently bloody), abdominal pain, fever, headache, nausea, and/or vomiting
Virus					
Norovirus	Contagious virus that causes vomiting and diarrhea.	From infected people to others, contaminated foods and surfaces	Any food or water	Yes	Protection from norovirus by washing hands often, rinsing fruits and vegetables, cooking shellfish thoroughly, staying home when sick

Parasites					
Taenia solium	Pork tapeworm	Raw or under-cooked pork meat with cysticercosis	Swine	Yes	Estimated prevalence is greater than 50 million people.
Ascaris spp.	Large intestinal roundworms	Water, vegetables, contaminated soil	Fresh produce	Yes	Drugs for treatment are cheap, readily available, and have few side effects
Cryptosporidium spp.	Protozoan parasites with many different hosts	Water, human contact in supply chain	Fresh produce, fruit juice, milk	Yes	Until recently had not been considered a trade risk
Toxoplasma gondii	Protozoan parasite belonging to the phylum Apicomplexa	Contact with undercooked meat or shellfish, water, contact with contaminated materials	Pork, venison, oysters, clams, mussels	Yes	Considered relatively benign
Chemicals					
Aflatoxins	Toxic secondary metabolites produced by some species of the *Aspergillus flavus* family.	Consumption of contaminated foods	Aflatoxins have been detected in grains, specifically maize, millet, and sorghum, as well as peanuts, and animal products such as meat, eggs, poultry, and milk.	Little evidence	Aflatoxins are a class 1 carcinogen. Aflatoxin contamination is widespread in Africa and other countries in Asia
Cyanide	Colorless gas or crystallized chemical	Breathing contaminated air, drinking water, food, soil, and smoking cigarettes	Cassava, lima beans, almonds, apricots, apples, and peaches	Little evidence	Occurs naturally in many foods
Dioxins	Toxic chemical that can be a byproduct in manufacturing, herbicides, and bleaching	Eating high fat foods, manufacturing byproduct, or exposure to herbicides	Dairy, eggs, meats, fish	Little evidence	Long exposure can cause skin conditions, liver issues, and elevated blood lipids

Table 2. Summary of funding institutions and projects.

Donor	Countries	Contribution
The Alliance for Accelerating Excellence in Science in Africa	Côte d'Ivoire, Kenya, Senegal, Tanzania	$775,293.49
The Bill & Melinda Gates Foundation		
(1) Partnership for Aflatoxin Control in Africa	Gambia, Malawi, Nigeria, Senegal, Uganda, Tanzania	$4,000,000
(2) Aflasafe Technology Transfer and Commercialization initiative	Burkina Faso, Gambia, Ghana, Kenya, Malawi, Mozambique, Nigeria, Senegal, Uganda, Tanzania, Zambia	$10,000,000
European Commission	Angola, Benin, Burkina Faso, Burundi, Cameroon, Congo, Côte d'Ivoire, DRC, Ethiopia, Gambia, Ghana, Guinea, Kenya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Nigeria, Rwanda, Senegal, Togo, Uganda, Tanzania, Zimbabwe	$11,063,225
Food and Agriculture Organization of the United Nations (FAO)	Burkina Faso, Cabo Verde, Chad, Gambia, Guinea-Bissau, Mali, Mauritania, Niger, Senegal	NA
World Health Organization (WHO)		
(1) Multi-country study to investigate multidrug-resistant (MDR) extended-spectrum (ESBL) and AmpC a-lactamase producing *E. coli* and *Salmonella enterica* in humans, food animals, meat products, and agricultural environments	Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Senegal, Sierra Leone, Togo.	NA
(2) Research on enteric pathogens from human, animal, and food sources including antimicrobial resistance	Burkina Faso, Burundi, Cameroon, Chad, Ethiopia, Gambia, Ghana, Kenya, Nigeria, Rwanda, Senegal, Seychelles, Togo, Uganda, Tanzania, Zambia	NA
FAO/WHO	Senegal	$232,350
Government of Luxembourg	Senegal, Burkina Faso	$1,173,708.85
United States Agency for International Development (USAID) – Other than Innovation Labs	Senegal	NA
USAID Feed the Future Innovation Labs	Senegal	NA

Note 1: The project "Aflasafe Technology Transfer and Commercialization" is also funded by USAID and the CGIAR Research Program on Agriculture for Nutrition and Health.
Note 2: NA means the number is not available.

Table 3. Feed the Future Innovation Labs (ILs) working in Senegal with no direct food safety objectives.

Feed the Future Innovation Lab	Objective(s)	Lead University / Director
IL for Food Security Policy	Increase public and private investments in agriculture by creating an efficient process to formulate, implement, and monitor agricultural policy with the Ministère de l'Agriculture et de l'Equipement Rural.	Michigan State University / Mywish Maredia
IL for Legume Systems Research	Explore which factors motivate farmers to adopt new cowpea varieties that will help turn nitrogen into a usable form for plants to help overall crop growth on farms. The project is conducted in three Institut Sénégalais de Recherches Agricoles research stations.	Michigan State University / Barry Pittendrigh
IL for Peanuts	● Study how the peanut value chain is affected by the number of children a woman has, her power in the household, and the climate shocks that happen in the regions of production. ● Examine the climatic and land-tenure constraints to youth participation in groundnut production and how these can be addressed via technology and policy options.	University of Georgia / Dave Hoisington
IL for Sorghum and Millet	● Develop new crop varieties that enhance productivity, food security, and farm incomes. Expand activities in entrepreneurship in local areas. ● The Innovation Lab for Sorghum and Millet implements five projects in Senegal.	Kansas State University / Timothy Dalton
IL for Sustainable Intensification	● Develop processes that can sustainably increase agricultural yield, specifically in regions with limited resources. ● Ensure food and nutritional security and establish sustainable farming systems for millet, leguminous crops (cowpea and groundnut), and small ruminant livestock (i.e., goats and sheep).	Kansas State University / Vara Prasad

Table 4. Estimates (median and 95% uncertainty interval) of the proportion of illnesses caused by bacterial, virus, or parasitic contamination in Africa through each exposure pathway.

Subregion	Food	Animal Contact (domestic and wild)	Human-to-Human Contact	Water	Soil	Other
***Campylobacter* spp.**						
AFR D	0.57	0.18	0.04	0.09	0	0.06
	(0.31–0.77)	(0.00–0.42)	(0.00–0.22)	(0.01–0.29)	(0.00–0.12)	(0.00–0.16)
AFR E	0.57	0.17	0.04	0.09	0	0.06
	(0.29–0.77)	(0.00–0.42)	(0.00–0.23)	(0.00–0.30)	(0.00–0.12)	(0.00–0.16)
Nontyphoidal *Salmonella enterica*						
AFR D	0.46	0.15	0.18	0.1	0.01	0.02
	(0.13–0.74)	(0.00–0.43)	(0.00–0.48)	(0.00–0.39)	(0.00–0.13)	(0.00–0.06)
AFR E	0.46	0.15	0.18	0.1	0.01	0.02
	(0.10–0.73)	(0.00–0.42)	(0.00–0.48)	(0.00–0.40)	(0.00–0.19)	(0.00–0.08)
Enteropathogenic *E. coli*						
AFR D	0.29	0	0.16	0.45	NA	0
	(0.02–0.62)	(0.00–0.33)	(0.00–0.51)	(0.12–0.76)	NA	(0.00–0.01)
AFR E	0.29	0	0.16	0.46	NA	0
	(0.01–0.62)	(0.00–0.32)	(0.00–0.51)	(0.10–0.76)	NA	(0.00–0.01)
Enterotoxigenic *E. coli*						
AFR D	0.33	0	0.13	0.45	NA	0
	(0.09–0.65)	(0.00–0.33)	(0.00–0.44)	(0.12–0.71)	NA	(0.00–0.01)
AFR E	0.33	0	0.13	0.45	NA	0
	(0.06–0.64)	(0.00–0.33)	(0.00–0.45)	(0.09–0.71)	NA	(0.00–0.01)
Norovirus						
AFR D	0.15	NA	0.68	0.07	NA	0.04
	(0.01–0.40)	NA	(0.37–0.89)	(0.00–0.38)	NA	(0.00–0.23)
AFR E	0.15	NA	0.68	0.07	NA	0.04
	(0.00–0.40)	NA	(0.38–0.89)	(0.00–0.37)	NA	(0.00–0.24)
Toxoplasma gondii						
AFR D	0.48	0.01	NA	0.11	0.36	NA
	(0.24–0.76)	(0.00–0.20)	NA	(0.00–0.37)	(0.07–0.57)	NA
AFR E	0.42	0.01	NA	0.16	0.38	NA
	(0.20–0.70)	(0.00–0.19)	NA	(0.02–0.41)	(0.05–0.58)	NA

Source: WHO (2015).

Notes: **Africa D** includes the countries Algeria, Angola, Benin, Burkina Faso, Cameroon, Cabo Verde, Chad, Comoros, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Madagascar, Mali, Mauritania, Mauritius, Niger, Nigeria, Sao Tome and Principe, **Senegal**, Seychelles, Sierra Leone, Togo. **Africa E** includes the countries Botswana, Burundi, Central African Republic, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Eritrea, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Swaziland, Uganda, United Republic of Tanzania, Zambia, and Zimbabwe. The values in parentheses correspond to the confidence intervals of the median values.

Table 5. Academic literature on aflatoxin contamination in Senegal, by crop studied

Authors and year	Area	Main Findings
Groundnuts		
Diop et al., 2000	Kaolack and Diourbel regions	The authors tested aflatoxin contamination in peanut oil and food prepared by small-scale production plants. They found Aflatoxins B1, B2, G1, and G2, with presence of aflatoxin B1 in 85% of the samples and an average of 40 ppb.
Kane et al., 2006	Sudan-Sahel zone	5 kg of in-shell peanuts from the variety 73-33 were collected from 10 farmers at the beginning of the storage period and then monthly for 7 months. The samples were transported to a laboratory and hand-shelled. Healthy peanuts were less contaminated by aflatoxin B1. The second least contaminated were immature and/ or wrinkled peanuts. 100 µg/kg or higher contamination was found in samples infested by millipedes or termites and in moldy and discolored samples.
Clavel et al., 2013	Experimental Station in Bambey	Authors tested aflatoxin resistance of two genotypes, 55-437 and Fleur 11. They found that water deficit occurring during the terminal phase cycle disrupts the maturation of pods, leading to their early desiccation before maturity. This poor drying exposes peanuts to infestation by *Aspergillus flavus* and causes a deficit of phytoalexins and phenolic compounds in the plant, which can lead to aflatoxin contamination. Very early maturing varieties that are ready for harvest in 80 days or less escape the end of season water deficit and also may avoid aflatoxin contamination.
Papa M. Diedhiou et al., 2012	markets of Thies	Using 20 samples, the authors found that groundnut kernels of good quality (sorted, mature, and healthy looking) had low aflatoxin levels and never exceeded the threshold of 10 ppb. Conversely, a mixture of immature, damaged kernels and kernels without seed coats had aflatoxins ranging from 0.55 to 15.33 ppb with 50% exceeding 10 ppb. Total aflatoxin levels were reduced by about 82.5% when groundnuts were submitted to roasting, made into peanut butter, and further steamed.
Watson et al., 2015	Nioro du Rip, Saint-Louis, and Mboro	Aflatoxins are widespread among adults in Senegal, although there are high variations among seasons and regions. In Nioro du Rip, larger plasma aflatoxin-albumin adducts AF-alb levels were found at harvest, while in Saint-Louis higher AF-alb levels were found post-harvest.

Dieme et al., 2018		Authors tested under laboratory conditions the resistance to *A. flavus* and aflatoxin contamination of 67 peanut genotypes. Total aflatoxin concentration was determined on the 15th day after inoculation using the mReader (R) method. There was a high variation of aflatoxin incidence and severity among the genotypes. Incidence was between 0 to 70% with only eight genotypes showing incidence less than 10%. Only genotype 12CS_104 showed aflatoxin concentrations below 4 ppb. Genotypes with low incidence and severity need to be tested under field conditions to verify their resistance to *A. flavus*.
Groundnuts and Maize		
Senghor et al., 2019	Diourbel, Nioro, and Tambacounda districts	Trials to test the efficacy of Aflasafe SN01 were conducted in Senegal. 72 fields were studied in 2010, 80 in 2011, 76 in 2012, 120 in 2013, and 188 in 2014. (1) Crops treated with Aflasafe SN01 had significantly less aflatoxins compared to control fields. (2) Crops from fields treated with Aflasafe SN01 had higher proportions of samples with less than 4 µg/kg aflatoxins both at harvest and after storage. (3) These results were used to prepare a dossier for the registration of Aflasafe SN01 with the regulatory agency responsible for registering pesticides in 13 countries of the Sahel. This organization approved the use of Aflasafe SN01 in May 2016 for aflatoxin control in maize and groundnuts across Senegal.
Maize and Sesame		
Papa Madiallacké Diedhiou et al., 2011	Guinea Savannah zone and Sudan Savannah zone	(1) Aflatoxin concentrations in maize and sesame kernels significantly vary by storage location, variety, shelling method, and agroecological zone. (2) Maize samples from the Guinea Savannah zone exhibited lower aflatoxin levels than those from the Sudan Savannah zone. (3) The maize variety 'Jaune de Bambey' showed high aflatoxin levels in both agro-ecological zones. (4) Aflatoxin content in machine-shelled maize was more than 10 times higher than in manually shelled or unshelled maize. (5) In both zones and in all storage systems, aflatoxin levels were lower in sesame than in maize.
Maize		
Bauchet et al., 2020	Vélingara Department	The authors set up an impact evaluation to examine the most cost-effective way to prevent aflatoxin contamination in maize. (1) Households who received training about aflatoxins, a hygrometer, a plastic sheet, and a PICS bag had the lowest

		aflatoxin levels and the largest number of samples below 10 ppb. (2) Providing only a plastic sheet was not statistically different from providing training only. (3) Providing a plastic sheet only was weakly different from the control group.
Rice		
Tang et al., 2019	Glazoue (Benin), Ndop (Cameroon), and Dagana (Senegal)	(1) Authors collected samples of white and parboiled milled rice and analyzed the factors affecting levels of three mycotoxins, fumonisin, zearalenone, and aflatoxins. In the areas of study, there is a high predisposition of rice stored in plastic woven or jute bags for moisture re-absorption (re-wetting) or moisture loss (drying), compromising rice quality. (2) Fumonisin concentration was positively influenced by the duration of storage only. (3) Zearalenone concentration was influenced by sample collection/storage location, processing type, and duration of storage. (4) Aflatoxin concentration was influenced negatively by storage room temperature and head rice but positively by impurities and chalky grains.