# Policy Options for Food System Transformation in Africa and the Role of Science, Technology and Innovation

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## 1 Introduction

Over the past decade, Africa's food systems have begun to transform, sparked by economic recovery, rising incomes, an expanding middle class, a growing population, rapid urbanization, globalization, and digitalization, among other factors. These key drivers are inducing fundamental changes in the dietary preferences and habits of consumers and the corresponding demand for food, with responses from the

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components of food systems, including food production, distribution and allocation (Tschirley et al. 2019). Yet, the shifts are coupled with a variety of challenges, including climate change, environmental degradation, low adoption of new technologies, and a growing energy deficit, amidst ongoing, rising resource-scarcity and limited financial resources, as well as socio-economic shocks, migration and youth unemployment. Covid-19 has added an additional strain on African food systems. Now is the opportunity to take stock, re-think and advance African food systems, to make them more sustainable, nutritious, resilient, and inclusive.

The UNFSS and COP26 have provided important moments for shaping the future of the region's food systems and ensuring that the much-needed agriculture-led growth and development agenda can simultaneously deliver on improving nutrition and health, saving lives, and protecting the environment. This includes addressing the usual elements of undernutrition and widespread micronutrient deficiencies and the growing problem of overweight and obesity that is increasing across the continent.

The chapter begins with a discussion of the context within which African food systems have developed and are now transforming, their key drivers, and the challenges and opportunities for this transformation. It concludes with STI and policy actions that are required to accelerate the transformation of food systems across the continent. The discussions are informed by literature and perspectives coming out of leading think tanks and universities in Africa.

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## 2 The Context of African Food Systems

African food systems are diverse, and draw on several traditional and modern technologies. Agriculture (including crop production, animal husbandry, fisheries and forestry, and processing) can stimulate economic growth and enhance economic transformation in Africa through raising rural incomes, creating jobs, and increasing government revenue (Baumüller et al. 2021). Increasing producers' and processors' incomes can positively affect poverty reduction and food security and nutrition (Baumüller et al. 2021). The emergence of processing sectors across the continent offers great potential to transform food systems, generate much-needed employment opportunities and positively impact nutrition. Furthermore, the African Continental Free Trade Area (AfCFTA) offers many additional opportunities for the development of food systems, including diverse livelihoods across the food system and the provision of safe and nutritious food to all on the continent using Africa's own resources and reducing the reliance on imports and development assistance.

Africa will require radical actions to reduce undernutrition, correct micronutrient deficiencies and simultaneously stem the tide of increasing overweight and obesity. Africa had the highest regional undernourishment rate in 2019 (19.1%, or more than 250 million undernourished people), more than twice the world average and growing faster than any other region (FAO et al. 2020). The proportion of undernourished people has risen by 1.5% since 2014 and is projected to rise to 25.7% by 2030 (FAO et al. 2020). More than 675 million people in Africa were food insecure (as measured by the Food Insecurity Experience Scale of FIES) in 2019 (FAO et al. 2020). Recent economic slowdowns and downturns partly explain the increase in hunger in several parts of Africa South of the Sahara (SSA) (FAO et al. 2020). The Covid-19 pandemic and other more localized shocks have worsened the situation, increasing the vulnerability of resource-poor food producers, particularly in already fragile regions.

The Covid-19 pandemic has disrupted food systems and livelihoods in Africa and threatens the significant gains over the past few decades in African development. The pandemic has led to transport restrictions and quarantine measures that restrict farmers' access to input and output markets and services, including human and animal health services (MaMo 2020). While data suggest that Africa has largely been spared the pandemic's scourge (Maeda and Nkengasong 2021), the long-term impacts have yet to unfold.

Food system transformation is required to ensure adequate incomes for producers and enable access to affordable, healthy diets[1] while managing increasing food demand from growing and rapidly urbanizing populations. Hence, the need to refocus the broader agricultural development agenda in Africa, in particular, under CAADP, to adopt a food systems lens. As food systems require cross-sectoral

[1] A healthy diet is health-promoting and disease-preventing. It provides adequate nutrients (without excess) and health-promoting substances from nutritious foods and avoids the consumption of health-harming substances (Neufeld et al. 2021a, b).

coordination beyond what was needed for CAADP, institutional innovation is also needed for Africa to rise to the vision of the AUC Agenda 2063 and the Food Systems Summit's aspirations.

## *2.1 Drivers and Opportunities*

The main drivers of food system transformation in Africa include sustained economic recovery and rising incomes, rapid urbanization, steady population growth, deepening globalization, and digitalization. Each of these drivers and how they contribute to the transformation of food systems across Africa are reviewed below.

(a) **Sustained, broad economic recovery and rising incomes**

The strong economic recovery observed across the African continent—with considerable growth acceleration since the early 2000s—is striking. Between 2000 and 2014, real per capita GDP has increased by over one-third on average, with faster growth of up to 100% or more in some countries. Furthermore, GDP per capita is projected to double by 2050. This positive growth trajectory has contributed to reductions in poverty and the emergence of a sizable, dynamic middle class. Rising incomes, accompanied by a growing middle class, are shaping the composition of consumer diets, driving an increasing demand for animal-source foods, such as dairy, eggs and meat. Between 2000 and 2010, per capita consumption of eggs, meat and milk in Africa grew by 24, 25 and 47%, respectively. By 2050, it is projected that per capita consumption of meat and milk will reach 26 kg and 64 kg per year, while close to 70% of total meat and milk consumption is expected to come from urban areas (MaMo 2020). Despite improvements in the quality of diets, hunger and malnutrition levels in Africa have remained high. While income growth is important for food security and nutrition, it is crucial to ensure that the food demands of high-income consumers are not catered to at the expense of the availability of more affordable foods for low-income consumers.

(b) **Population growth and distribution**

Countries in SSA are expected to account for over half of the world's population growth between 2019 and 2050. Further, by the end of the century, the continent is projected to add more than 1 billion people. With higher food demand, Africa is experiencing a widening food import gap, putting pressure on food production systems and scarce foreign exchange resources. Moreover, Africa's youth population is growing faster than other age groups, providing an opportunity for a demographic dividend with potentially positive effects on food system transformation and economic growth. Meeting the nutritional and employment needs of a growing young population will be key to reaping the demographic dividend. A rapid increase in rural density across the continent, particularly in peri-urban centers, is contributing to the transformation of agriculture and the diversification of rural economies—thereby influencing the structure of farming (Allen 2015). In some countries, the number of medium- and large-scale farms is increasing, and in others, they already account for a sizable and rising portion of total farmland. Agribusinesses and downstream food systems are thus responding to population growth and urbanization in dynamic ways.

(c) **Urbanization**

Urbanization across Africa has reached the levels of other regions in the world and has continued to grow at a rate of nearly 4% per annum. While there were only two African cities with more than a million inhabitants in 1950, this increased to 50 in 2010 and is expected to nearly double by 2025 (Conway et al. 2019). An important feature of Africa's urbanization, with significant implications for food system transformation, is that it is being driven by the emergence of many small cities or rural towns.

Africa's total urban food market is projected to reach US$ 150 billion by 2030, with potential opportunities for smallholder farmers to capture as much as US$30 billion (AUC/NEPAD 2008). Urbanization in Africa is driving increased demand for processed, ready-to-cook, or ready-to-eat foods, such as couscous, millet flour, garri (cassava flakes), and ultra-processed foods. By 2040, the share of processed foods is expected to increase five to tenfold compared to 2010 and will account for nearly 75% of the demand for staple foods (Conway et al. 2019). However, urbanization and the associated changes in consumer lifestyle and diets can increase overweight and obesity (Ziraba et al. 2009). There is a widespread increase in the consumption of refined or highly processed foods, as well as of sugar, salt, fats, and oils. At the same time, growing attention to public health and diets presents opportunities to decrease the prevalence of obesity and diet-related chronic and non-communicable diseases, such as diabetes and heart diseases.

(d) **Globalization, the large-scale food industry, and trade**

Globalization and the growth of the large-scale food industry, including the rapid development of supermarkets, are driving changes in the supply and demand of food. Moreover, trade policies and processes that facilitate or mitigate the expansion of trade are contributing to the globalization of food trade and increasing the demand for food quality and safety standards. These drivers are closely linked with urbanization, rising incomes, and a growing middle class, as changing environments and preferences interact to influence dietary patterns. Domestically, the need to feed Africa's growing cities is reshaping farmers' access to markets, starting with those closest to towns and moving outward into remote areas. The rise of secondary cities is expanding market access and extending value chains into previously hard-to-reach areas. To harness the benefits afforded by greater domestic, regional and international trade, it is necessary to raise the productivity of smallholder famers, improve the quality of their produce and boost competitiveness of domestic processing sectors.

## 2.2 Threats and Challenges

While a new optimism has emerged about the potential of food system transformation, African food systems continue to face several challenges, including low levels of investment in agriculture, climate change, environmental degradation, limited adoption levels of yield-increasing technologies, slow adoption of biotechnology, and an energy deficit.

(a) **Climate change and environmental degradation**

Climate change is a major risk to food system transformation. It presents significant challenges to African agriculture and threatens recent progress in increasing productivity and reducing poverty and hunger. The combination of rising temperatures and changing precipitation patterns is projected to result in a broad range of impacts, including increases in the frequency of weather volatility and extreme weather events, rising sea levels, changes in the incidence of agricultural pests and diseases, adverse effects on crop productivity, and a general decline in the production of several key crops in the coming decades (Pereira 2017). By 2050, climate change is expected to leave more than 38 million more people at risk of hunger in SSA than would otherwise be the case, particularly in Eastern Africa. In addition, more than 4 million children under five years of age are projected to face malnutrition (Wiebe et al. 2017).

Even though the intensification and homogenization of food systems have contributed to increases in per capita agricultural outputs, they have resulted in major degradation of soils and a loss of biodiversity around the world, including in Africa. Several studies show not only the significant impacts of degradation on agricultural production in SSA (hence, threats to future food security), but also the need for solutions that are tailored specifically to local agro-ecological conditions and farming systems (Bindraban et al. 2012). Ensuring food security and safeguarding biodiversity should not be seen as incompatible goals, but rather as synergetic, given the interdependence between agriculture and biodiversity, as well as the important role that each plays in preserving the other.

(b) **Limited adoption of improved production technologies**

The expanded use of modern inputs, such as improved seeds, irrigation, and mechanization, have significant potential to accelerate food system transformation, but the intensity of input use in Africa still lags behind that of other regions (Sheahan and Barrett 2017). Africa has the least mechanized food systems in the world: farmers have ten times fewer mechanized tools per farm area than farmers in other developing regions, and access has not grown as quickly as in other regions. However, some countries have experienced more dynamic growth in mechanization, by emphasizing equipment rental or service hiring markets, improving access to credit, promoting domestic manufacturing, and improving the environment for public-private partnerships to thrive (MaMo 2019b). Mechanization in African food systems needs rethinking and fresh strategies. Its success will not only be about technology, but also organizational innovations, such as reliable services and cooperation arrangements for and with farmers. Opportunities for mechanization must be harnessed at each stage of the agricultural value chain and, when done right, can and should be employment-enhancing, not labor-replacing (MaMo 2018).

(c) **Slow adoption of biotechnology**

Biotechnology, including improved seed varieties, has not been widely embraced across Africa. Investment in technical expertise and the development of institutional infrastructure for harnessing biotechnology and fostering adoption, particularly among smallholders, are a priority. Through crop biotechnology and genomics, scientists are designing and developing crops with higher yields, additional nutrients, and enhanced tastes. The power of modern agricultural biotechnology and genomics in transforming African food systems into a force of economic growth, creating wealth in the rural space and beyond, feeding a growing African population and conserving resources for future generations, cannot be ignored.

(d) **Energy deficit**

Currently, Africa faces the highest costs of electricity provision in the world, and large shares of the population, particularly in rural areas, remain unconnected to energy grids (Badiane et al. 2020). Recent figures show that 580 million people in Africa still lacked access to electricity in 2019 (Ringler and Brent 2020). Policies that explore promising off/mini-grid solutions that can meet the needs of smallholder farmers, agro-industries and households in remote areas should be explored, coupled with fiscal incentives, including reduced import duties. Expanding access to alternative sources of energy, such as solar, wind and biogas, can help boost food security across the continent by stimulating sustainable agricultural development and improving water security, thereby accelerating rural and economic growth (Ringler and Brent 2020). One promising example is cluster-based approaches to agricultural electrification through "farm blocks" that are equipped with basic infrastructure and complemented by industrial cluster zones for agricultural processing (MaMo 2019b).

## 3 Transforming Food Systems in Africa Through STI and Policy Innovations

Adopting an integrated approach to transforming food systems could provide multiple opportunities for the development of African economies and societies. With her rich diversity of production systems, significant biodiversity and strong cultural association with traditional diets that are, for the most part, nutritious and healthy, the development of Africa's food systems has the potential to build healthier, more sustainable and more equitable systems.

Any change in food systems will lead to a multiplicity of changes affecting nutrition, health, welfare and the environment. The health implications, welfare outcomes (such as through livelihood outcomes, wages and incomes) and dietary patterns' environmental footprints are strongly dependent on how foods are produced and processed. STI can help support food system development in ways that protect resources, provide livelihood opportunities and improve incomes across the system, while delivering more nutritious and healthy diets.

Policies and practices that promote adaptation to rapidly changing climate conditions are urgently required. A key intervention is the adoption of improved agricultural technologies for sustainable intensification (Wiebe et al. 2017). Widespread adoption of climate-smart practices, such as integrated soil fertility management, drought- and heat-tolerant crop varieties, integrated crop-livestock management, and conservation agriculture, should also be encouraged (Nkonya and Koo 2017; Conway et al. 2019). While these climate-smart agriculture practices show promise in terms of higher productivity and improvements to food security, their adoption by smallholder farmers in SSA is constrained by limited access to inputs and information, markets, and risk-management tools. Major investments in research and technology, coupled with institutional and physical infrastructure, are therefore needed.

Digitalization has significant potential to improve efficiency, equity, and environmental sustainability in food systems across Africa. The use of digital and data-driven technologies at each segment of agriculture value chains can guide and support decisions on production methods, value chain optimization, and storage methods so as to avoid food waste and loss. For many farmers, access to output and input markets has increased as a digital revolution is allowing markets to connect faster.

The private sector is already playing a major role in accelerating the development of promising technologies and solutions in the food and agriculture sector. Innovation funds, often in the form of grants, are now being used to create platforms for innovative activity by providing incentives to improve collaboration and the quality of services offered. Placing digitalization at the center of food system transformation strategies and policies will be key to harnessing its cross-cutting innovative power. Moreover, data derived from digitalization efforts offer opportunities to design better-informed policies for food system transformation at scale.

It should be noted that the biotechnology revolution arose from the convergence of advancements in the biological, physical, engineering, and social sciences. In terms of food systems, what converges is the technical reinforcement of these advancements in terms of product optimization and formulation and the mutual benefit of different disciplines. Food systems approaches will bring about new innovations from transdisciplinary perspectives to solve unique problems.

### 3.1 Improving Production Efficiency and Restoring and Sustainably Managing Natural Resources

Within the context of a growing demand for food (including animal-sourced foods), improving the efficiency of production systems is necessary, given constraints on land and resource availability and the relatively small land plots in most of Africa (Lowder et al. 2016). At the same time, it is also an environmental imperative.

Restoring soil fertility is a major priority for agricultural transformation in Africa. Continuous cropping and unsustainable cultivation practices driven by shrinking farm sizes and increasing food demand threaten future food supply in Africa (Jayne et al. 2014), limiting the potential benefit from yield gains offered by plant genetic improvement (Tittonell and Giller 2013). Appropriate soil improvement practices and informed production choices are essential to prevent further degradation. A holistic and integrated strategy is needed that focuses on raising organic matter and improving moisture retention (Kihara et al. 2016). The soil microbiome affects how plants react to environmental stresses such as high salinity and low water availability and diseases. The isolation of microbial strains and modern high-throughput sequencing technologies are being used to catalogue microbial species associated with plants in different soils, including arid and saline soils (Wild 2016). The development of next-generation crop varieties should simultaneously select beneficial characteristics in both the plant and the microbiome to improve soil fertility and crop yields (Gopal and Gupta 2016). Research is also needed to develop protective seed coatings to protect plants from soil-borne pests and pathogens while also providing micro bio-fertilizers (Rocha et al. 2019).

Sustainably managing water use for food production, food processing and industrialization, as well as safe drinking water, sanitation and hygiene, is critical for successful food system transformation. The demand for these resources competes for the available water that can be eased through use of appropriate technology and policies. Urbanization will place increased pressure on water demand and compete with water for food production, while urbanization and industrialization also pose threats to overall water quality.

Irrigation use remains low in Africa. Yet, evidence shows that average yields on irrigated areas are 90% higher than in nearby rainfed areas. Investment and innovation will be necessary for low-cost yet efficient irrigation options to mitigate the impact of water scarcity and expand the availability of diverse foods year-round. Hydroponic production, with recirculation of water and nutrients in a closed system, can reduce water consumption (Al Shrouf 2017), while drip irrigation delivers just the right amount of water, at a specific time, to a precise spot where the water will be best absorbed by the plant, producing "more crop per drop." Promoting the use of renewable energies in water desalination for agriculture use could offer competitive cost options for the delivery of modern energy and increase the use of non-conventional water resources to guarantee long-term food security and socio-economic stability.

Many energy-generation systems also depend on water sources for hydroelectric power, the cooling of power plants and hydraulic fracturing. Several countries with large-scale irrigation programs source water from aquifers, threatening long-term sustainability, and possibly leading to conflict over water in the future. Competition for water needs to be eased using appropriate technology and policies to protect and manage water resources (including river basins and lakes). Water-harvesting and storage are necessary to support crop and livestock production. More innovation is required in recycling wastewater to increase the overall availability of water. The desalination of seawater offers one option to increase the availability of water for human consumption and agricultural production. However, this technology is still expensive and results in waste (high salt concentrations) that poses additional environmental problems (Ahmadi et al. 2020).

Livestock is an important element of millions of people's livelihoods in Africa's pastoralist, mixed crop-livestock farming and commercial systems, offering multiple opportunities for income and employment. Increases in demand for animal products in African countries outpace supply. Meeting this demand will require substantial increases in production while reducing the environmental footprint of livestock production. Livestock (including poultry, swine, sheep, goats, cattle and rabbits) are good sources of high-quality animal protein with rich amino acid profiles (NASAC 2018). They also provide much-needed nutrient-dense foods, vital to overcoming the high rates of child malnutrition in Africa.

However, globally, livestock accounts for 14.5% of all greenhouse gas emissions (cattle for 60% of these), with emissions linked to food digestion and feed production dominating emissions from ruminants (Gerber et al. 2013), and about a third of the freshwater footprint for agriculture (Mekonnen and Hoekstra 2012). Although Africa's livestock sector is still primarily extensive (rather than intensive, industrialized production), this may change as the demand for animal-sourced foods increases with shifting urbanization and changes in income in middle-income countries. Climate change could affect future grazing capacities, lead to more migration of animal herds, and increase zoonotic disease incidence (MaMo Panel 2020).

Livestock genetic improvement programs, interventions to increase carbon sequestration in grasslands and improved management of grazing lands could significantly increase productivity and reduce greenhouse gas emissions (Gerber et al. 2013; Henderson et al. 2015). The use of high-quality forage grasses and legumes offers a wide array of benefits, including higher livestock and crop productivity, restoration of degraded land through the accumulation of organic matter in soils, and improvement of soil fertility through the fixation of atmospheric nitrogen, the inhibition of nitrification in the soil and a year-round supply of feedstock (Rao et al. 2015). Indigenous feed resources can be incorporated into feeds to promote sustainability. The available genetic variability of forage plants is still largely untapped and underutilized (Sandhu et al. 2015). Drought-tolerant *Brachiaria* grasses originated primarily in natural grasslands in Africa, yet they have only recently been re-introduced for commercial cultivation in African countries at a significant scale. It has been estimated that cows reared in *Brachiaria* pastures could increase productivity by up to 40% in Kenya and Rwanda compared to native grasslands, with spillover benefits further down the value chain (Maina et al. 2020).

Emerging challenges in animal health include improving resistance to disease and combating the misuse of antibiotics in animal production systems (Kimera et al. 2020). An example of such pests is the trypanosome parasites. Trypanosomiasis greatly restricts cattle rearing in 32 countries of SSA, leading to losses due to lost animals and animal products of between US$1 billion and US$6 billion annually (Yaro et al. 2016). The development of conventional vaccines against the parasite has been thwarted by trypanosomes' ability to continuously change the antigenic properties of their surface coat and evade attack by the host's immune system (Radwanska et al. 2008). The discovery of innate resistance to trypanosomiasis in some African wild animals linked to the presence of a protein in their blood that kills trypanosomes, called APOL1, has opened new avenues of research (Del Pilar Molina-Portela et al. 2005), offering opportunities to develop effective vaccines.

Fish is an important source of food and nutrients, as well as livelihoods, in Africa. Fish provides 19% of animal protein in African diets (Chan et al. 2019). Africa is a net importer of fish (Chan et al. 2019). A threefold increase in production is needed to meet expected demands in fish (Chan et al. 2019). Aquaculture, an emerging sector on the continent, holds great potential for rapidly increasing the amount of available protein. Aquaculture production in Africa expanded at an average annual rate of 11.7% between 2000 and 2012 (nearly twice the global average rate of 6.2% (FAO 2014). Given the spatial and environmental constraints, this will require improvements in efficiency, husbandry and increased investment in domestication and development of new species for commercial production, alongside the genetic improvement of existing commercial stocks. Initiatives to genetically improve fish for aquaculture have so far been quite limited. Of the 400 species cultured, 90 are domesticated, and, of these, only 18 (5%) have been the subject of significant genetic improvement programs (Teletchea and Fontaine 2014). Genetic improvement can also reduce the environmental footprint of aquaculture.

### *3.2 Optimizing the Utilization of Indigenous Crops, Livestock, Fish and Underutilized Foods*

Africa has over 2000 plant species that include domesticated and semi-domesticated native grains, roots, fruits and vegetables. These are considered to be "lost" species for rediscovery and exploitation in modern food systems, owing to their natural health and nutritional benefits and a variety of adaptive and resilient properties (National Research Council 1996). Many indigenous crops have multiple edible parts such as leaves, fruit, seeds and roots. Many indigenous African livestock, fish and plant breeds are resilient to many risks and adverse growing conditions (Mabhaudhi et al. 2019). But they tend to be viewed as famine foods, foraged and turned to by the poor in adverse situations. Yet, many of these foods are described as 'superfoods.' Optimal utilization of nutritious indigenous and traditional foods holds the potential for diversifying Africa's food systems, especially if more of these can be domesticated and produced in larger quantities. There is an urgent need to create pride in and demand for these foods and investment in research and technology development across the food system to integrate these resources into the daily food basket of African communities.

Although not widely adopted in Africa, biotechnology (techniques for improving plants, animals, and microorganisms) offers many opportunities to improve productivity, overcome abiotic (such as drought) and biotic stresses (diseases and pests), and save time and effort for farmers in Africa. For example, genetically modified crop varieties are labor-saving and reduce agricultural production's drudgery—especially for women, who are often saddled with more labor-intensive tasks such as weeding (Gouse et al. 2016). For instance, African farmers can benefit significantly from the adoption of Bt cotton. However, the share of farmers that stand to gain from the introduction of Bt cotton technology will be largely influenced by whether governments and technology innovators support appropriate incentives and address institutional and socio-economic barriers. Knowledge flows to and from farmers will play a critical role in the proper deployment of biotechnology (Falck-Zepeda et al. 2007). Furthermore, building the technical expertise in Africa to harness and safely deploy biotechnology for communities and the environment will be important.

Biotechnology can support food security in the face of major challenges such as declining per capita availability of arable land; lower productivity of crops, livestock and fisheries; heavy production losses due to biotic (insects, pests, weeds) and abiotic (salinity, drought, alkalinity) stresses; significant postharvest crop damage; and the declining availability of water. Biotechnology techniques that could be applied include tissue culture; marker-assisted selection, which entails the development of genetic markers to fast-track selection of natural traits in plant breeding; the "omics" (sciences such as genomics, proteomics and transcriptomics); the development of diagnostics; genetic modification; and a newer set of tools collectively referred to as the new plant breeding technologies (NASAC 2018).

### *3.3 Innovation in the Storage, Processing and Packaging of Foods*

Transformation of the food system in Africa demands that we harness STI to promote product diversification with nutritious foods; processing to extend shelf life and make healthy foods easier to prepare; improved storage and preservation to retain nutritional value and ensure food safety; and innovations to extend seasonal availability and reduce postharvest losses (including aflatoxin) and food waste (Hendriks et al. 2021).

The emergence of the food processing sector is accompanied by a lengthening of agricultural value chains. From traditionally short chains limited to home-based processing and confined predominantly to rural areas, the changing value chains now primarily supply small towns and large urban centers with a range of branded, ready-to-cook or -eat foods (Conway et al. 2019). Urban-based value chains are fueled by the introduction of new processes for producing and distributing traditional foods outside of the household setting through specialized enterprises (Hawkes et al. 2017). This offers new employment opportunities in processing, distribution, packaging, and marketing across food value chains, as well as increased incomes for farmers. Strengthening the links between producers and processors is important to facilitate firm growth and benefit smallholder farmers.

Postharvest handling and technologies offer opportunities to reduce food losses and waste, particularly in the context of Africa, where cold chains and refrigeration are largely non-existent (MaMo 2019b) and seasonality leads to gluts and shortages of perishable goods. Many of these losses can be prevented through proper training and better handling of goods, the adoption of appropriate tools or technologies, sound policies and marketing-related improvements (Stathers et al. 2020). More investment is also needed in developing and making available solar driers and agro-processing equipment such as shellers and de-pulpers.

Food processing has the potential to contribute to the reduction of postharvest losses, enhancement of food safety and quality, creation of diversity, and stabilization of the food supply, reducing the prevalence of seasonal hunger and improving market access. Food processing can generate jobs and increase the retention of organic waste in farming areas. Even simple processing methods can transform perishable crops into a range of convenient, storable, value-added products, which meet the needs of expanding markets (Muyonga 2014).

Processing foods may smooth supplies, but can create deleterious health consequences (overweight, obesity and non-communicable diseases), depending on their ingredients (trans fats, high sugar and sugar alternatives, and excessive preservatives and other additives) (Pot et al. 2017). On the other hand, processing can also be used to create products that address specific nutrition needs. By blending staples and foods with complementary nutritional value and applying suitable processing procedures, it is possible to develop nutrient- and energy-enhanced foods to supplement prevailing nutritionally inadequate diets, particularly important for infants and young children.

Food safety is critical to the advancement of food systems. Poverty exacerbates the problem, since it leads to overdependence on one foodstuff and may lead to the consumption of contaminated foods because of the lack of alternatives (Shephard and Gelderblom 2014). Evidence on foodborne disease (FBD) in low- and middle-income countries (LMICs) is still limited, but important studies in recent years have broadened our understanding. Most of the known burden of FBD disease in low- and middle-income countries comes from biological hazards, primarily from fresh, perishable foods sold in informal markets (Grace 2015). Testing is often expensive and constrains the approval, distribution and export of foods. The lack of suitable regulations to prevent food contamination, or their poor enforcement when regulations exist (often applied to export goods, but not the domestic market), combined with the low levels of capacity for detecting food toxins, are serious concerns. Rapid and cheap out-of-laboratory analytical techniques designed for field conditions can offer solutions to these problems (Shephard and Gelderblom 2014). Examples are fluorescence spectrophotometry for quantifying mycotoxin levels in grains and raw groundnuts and the Lab-on-Mobile-Device (LMD) platform that can accurately detect mycotoxins using strip tests (Dobrovolny 2013).

More research and development is needed towards packaging solutions to extend the shelf-life of food, thereby reducing enzymatic activity and the growth of microorganisms and preventing moisture loss and decay. Thermal processing has been widely employed in the food industry for food safety assurance and extending product shelf-life by inhibiting or deactivating microorganisms (Caminiti et al. 2011; Stoica et al. 2013). Other technologies that could have significant benefits for food safety in Africa include non-thermal inactivation technologies such as electromagnetic fields, pulsed electric fields, high-voltage discharge, pulsed light, ionizing radiation, microwaves and cold plasma (NASAC 2018). Hybrid technologies and combinations of these methods have not yet been applied to the indigenous food industry, but could hold promise for transforming African food systems.

### *3.4 Improving Human Nutrition and Health*

Making more nutritious food options available to a wide range of consumers is another pathway to influencing nutritional outcomes. This can include public and private sector investment in research and innovation of technologies and processes that improve foods' nutritional value. Recent advances in gene sequencing technologies enable investigation of the complex gut biome at both the genetic and functional (transcriptomic, proteomic and metabolic) levels and can map microbiome variability between species, individuals and populations, providing new insights into the importance of the gut microbiome in human health (Brunkwall and Orho-Melander 2017). Together with studies of traditional diets that include a wide range of herbal, medicinal and fermented products from Africa's wealth of indigenous foods, these offer opportunities for understanding how foods and the gut biome interact to protect human health and immunity.

Food fortification initiatives such as salt iodization, adding vitamin A to cooking oil and multivitamin mixes to maize flour, as well as the bio-fortification of crops such as the varieties of vitamin-A-enriched orange-flesh sweet potato, offer options for reaching a high proportion of the population. More research is needed into which African crops could benefit from breeding programs for bio-fortification to diversify the food basket and preserve the genetic diversity of nutritious traditional crops. Breeding, processing and additives such as prebiotics and probiotics offer the potential for enhancing the bioavailability of nutrients for absorption and metabolism (Markowiak and Śliżewska 2017) or decreasing the concentration of antinutrient compounds that may inhibit the absorption of nutrients (for example, phytates and oxalates) (Popova and Mihaylova 2019).

### 3.5 Addressing Equity and Vulnerability at the Community and Ecosystem Levels

Several socio-economic, cultural and demographic factors continue to drive inequalities among and within societies and limit the potential for some to benefit from actions aimed at improving livelihoods. This is coupled with political factors and decisions that are essential causes of inequality and power imbalances, severely constraining the ability of food system transformation to deliver sustained poverty reduction and sustainable, equitable livelihoods in Africa (Neufeld et al. 2021a, b). These existing inequities are further exacerbated by conflict, protracted crises and climate change, while the ongoing Covid-19 pandemic has dramatically exposed countries' pinch points and societies' vulnerabilities (Bron et al. 2021; MaMo Panel 2021). To ensure that food system transformation in Africa is not only sustainable, but also equitable, the structures that continue to enable and exacerbate inequities need to be urgently addressed.

One effective solution is to boost the opportunities and capacities of the most vulnerable, through redistributing resources more equitably (e.g., land, incomes, social protection), ensuring quality education, enabling progressive, and not regressive, taxation, and facilitating better targeted state infrastructure investments, among other approaches (Neufeld et al. 2021a, b). This must go hand in hand with decision-making that is more equitable and accountable to those who are most negatively affected by current food systems and their outcomes. Progress in advancing equitable livelihoods must hence be made in several key areas. According to Neufeld et al., this includes solutions that (i) are rights-based; (ii) ensure long-term investment for structural changes; (iii) directly inform local and national policy and programs; and (iv) enhance the development and equitable deployment of contextually relevant innovation and technology that better build on and learn from indigenous knowledge.

### 3.6 A Data Revolution for Improved Preparedness and Accountability Systems

The complex nature of food systems demands transdisciplinary collaboration and inter-sectoral governance. ICT can enhance learning among stakeholders, as well as between disciplines, to support innovation and the emergence of practical technologies that arise from transdisciplinary collaboration.

Evidence-based policies and planning require extensive and up-to-date data. There is an urgent need to strengthen national and regional institutional capacities for knowledge, data generation, and management that support evidence-based planning, implementation, and monitoring and evaluation (Bahiigwa et al. 2016). ICT innovations also offer multiple opportunities for improving food systems that could support the establishment of “big data” systems, analysis and reporting of cross-sectoral data, and monitoring and evaluation of implementation. Therefore, more significant investment is needed in more and better data, and inclusive annual national and subnational reporting mechanisms need to be developed and implemented to assess progress on commitments for food security and nutrition outcomes and actions in a timely way (Hendriks et al. 2021).

Collecting, managing and reporting data requires extensive information systems. “Big data” systems offer opportunities to analyze vast datasets that reveal patterns, trends and associations, especially in multi-sectoral applications such as those seen in the SGDs and national performance and monitoring situations related to food systems through innovative approaches and algorithms. Some applications include fraud and risk detection and logistic planning in programs and price comparisons, as well as predictive and proactive health disease and health management systems (NASAC 2018).

Public awareness of the problems, hazards and solutions is essential. Cloud computing allows for crowdsourcing and the active participation of citizens in mutual accountability systems and the provision of highly disaggregated geo-referenced data that can play an important role in monitoring contexts such as climate change, disease patterns and early warning systems. Communication science offers opportunities for exploring how to deploy digital media and improve communication systems to share knowledge at all levels. The role of ICT in the rapid identification of pests and diseases and the mapping of their locations and spread are important tools for managing and mitigating the inherent risks they create (Christaki 2015) and for increasing the awareness and preparedness of farmers, especially as much of the African food chain is informal. Investment in qualified staff within government, extension, and supporting research institutes is crucial, with a particular need for investment in young researchers and entrepreneurs.

Comprehensive soil mapping is necessary to address the deficiencies through appropriate soil improvement practices and the cultivation of the most suitable crops for each area. Overlaying these with weather and crop suitability maps can provide hands-on information to farmers through mobile technology. Mobile technology could be used to improve early warning systems and the dissemination of knowledge. One example is the Participatory Integrated Climate Services for Agriculture, which can help farmers make informed decisions based on accurate, location-specific, climate and weather information combined with locally relevant crop, livestock and livelihood options and participatory tools (Dayamba et al. 2018).

Satellite Earth Observations, such as Africa Agriculture Watch, are novel opportunities born out of the ICT revolution that, combined with in-situ data, provide a source of consistent and reliable information to benefit the water, energy, and food sectors. Such observations are necessary to begin understanding the complex feedback processes between the natural environment and human activities (FAO 2014).

ICT can solve many of the current constraints around access to information, data analysis, predictions and early warning. Innovations in mobile technology can overcome many trade- and market-related information challenges, link farmers to markets and provide mutual communication among producers, consumers and researchers. ICT applications and advances in digital banking offer opportunities for solving some of these constraints.

Hence, the digitalization of the agriculture sector needs to be placed at the core of national agricultural growth and food system transformation agendas to harness its cross-cutting innovative strength. By developing national digital agriculture strategies along with required public investments, governments can set out solid long-term visions for the design, development, and use of new technologies along the food system value chain.

Digital innovation hubs create the innovation ecosystem that is needed to spur the digital transformation of Africa's food systems, while providing opportunities and support for young people in the development of locally suitable technologies and digital solutions. More investment and support need to be provided to create more innovation hubs across the continent that are dedicated to developing solutions focused on food system transformation.

Finally, to ensure that digital applications and services meet quality standards, research centers can play an active role in the evaluation and impact assessment of specific technologies and e-services in rural areas. This would allow governments and the private sector to bring to scale those programs and interventions that are proven impactful and beneficial to rural communities. Quality control and standard-setting of new technologies, digital tools, and services require the attention of business associations and governments.

### *3.7 Leveraging African Research and Science and Improving Education and Training*

Food system transformation is a relatively new concept. As such, investment in research and development for the transformation of food systems in Africa needs to be significantly increased. One option is to develop an African funding base to support supranational research activities. Think tanks and research institutions need to be considered public goods that foster continued dialogue and supply of innovative approaches and solutions to the challenges that the food systems face. Crucially, African research institutions need to be equipped to support governments in developing their own evidence-based policy priorities and science, technology, and innovations for food system transformation, coupled with scalable solutions. This ought to occur in tandem with continued exchange and constructive dialogue with other regions in the world to improve public policy. The need for permanent dialogue and exchanges calls for the creation of policy labs that allow for innovation and experimentation and learning from past failures.

### 3.8 Capacity Strengthening of Institutions and Mutual Accountability

Governments must be held accountable for their commitments to invest in integrated approaches and food system transformation. Mutual accountability country processes, including the Biennial Reviews and the agriculture Joint Sector Reviews, two major innovations under the CAADP agenda, remain critical for this. Mutual accountability will be crucial for improved policies and better outcomes around food system transformation and will ensure that policies respond to the needs of all stakeholders, including the vulnerable and marginalized.

To deliver on the ambitions and targets set out under the African Union Agenda 2063, CAADP and the SDGs, capacities for implementation, monitoring, and evaluation need to be strengthened. Poor institutional capacity has been identified as one of the major barriers to the successful implementation of the program. Countries will, therefore, need to invest more in building the requisite capacities to transform agriculture and food systems and commit to inclusive, technically rigorous, and comprehensive mutual accountability processes. The biennial review and the joint sector review processes hereby constitute best practice approaches that need to be built upon to encompass all elements of food system transformation.

## 4 Conclusions

As African governments embrace a food systems approach to policy design and implementation, specific attention needs to be paid to transforming food systems in a way that enhances nutrition outcomes, improves livelihoods and protects and enhances the environment. As this chapter shows, this can be achieved through policies and interventions targeted at food and agriculture trade, infrastructure development, finance, and science and technology for food systems, as well as capacity and skill strengthening. Science, technology and policy innovations offer many promising opportunities for food system transformation in Africa.

The chapter emphasizes the importance of evidence-based policies that understand and harness the synergies and trade-offs among food, health, water, energy and ecosystems, that provide alternative solutions for agricultural extension and advisory services, and that promote organizational innovations at the production, industry and downstream levels of supply chains that are lean, agile, resilient and green. Comprehensive and differentiated policy reforms for integrated food systems across Africa, as well as improvements in governance and management for better outcomes, are critical.

At the same time, modern science can unlock the potential and protect the heritage of Africa's nutritious food sources and ensure sustainable and diverse diets. Changing the path of future food systems in Africa will demand a structural transformation (transitioning from low productivity and labor-intensive economic activities to higher productivity and skill-intensive activities) of food systems and considerable value chain development. The mandate and operations of S&T institutions are necessary to enhance their contribution to the exploitation of S&T for sector transformation.

The context-specific essential STI and policy solutions relevant to transforming food systems in Africa relate to:

(a) Raising production efficiency and restoring and sustainably managing degraded resources
(b) Innovating in the storage, processing and packaging of foods
(c) Improving human nutrition and health
(d) Addressing equity and vulnerability at the community and ecosystem levels
(e) Fostering a data revolution for greater access to information and transparent monitoring and accountability systems
(f) Leveraging African research and science and improving education and training
(g) Strengthening the capacity of institutions and mutual accountability

The Food Systems Summit offers opportunities for stakeholders in African food systems to reflect on the role STI can play in transforming food system outcomes to improve the supply of safe and nutritious food for all while restoring and protecting the degradation of natural resources to ensure sustainability for future generations.

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