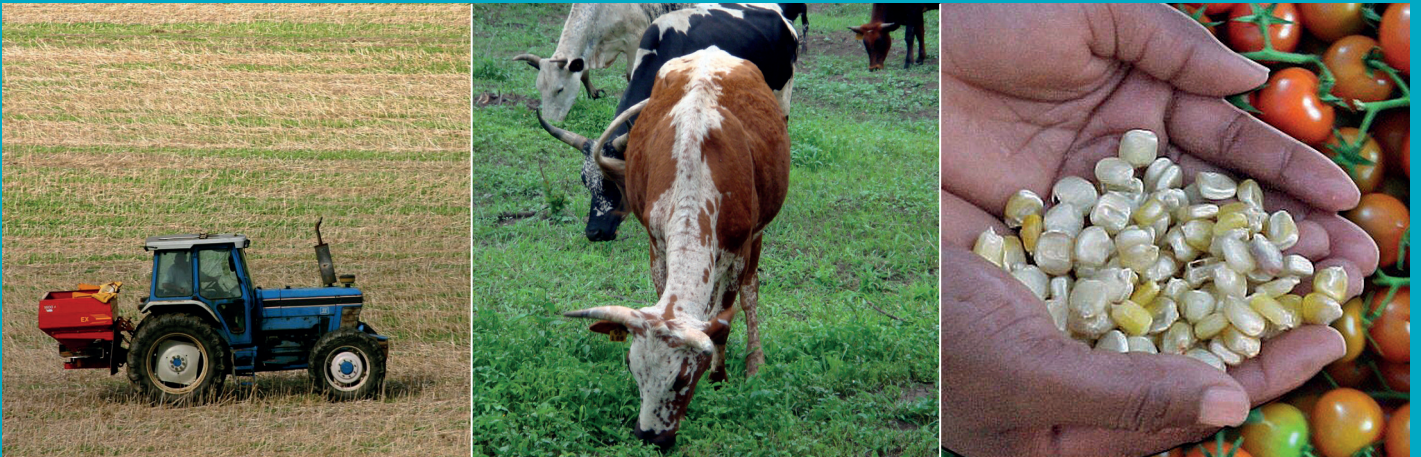


Opportunities and challenges for research on food and nutrition security and agriculture in Africa



NASAC
May 2018

ISBN: 978-9966-112-00-2

This report can be found at
<http://nasaonline.org/>

NASAC

The Network of African Science Academies (NASAC) was established on 13th December 2001 in Nairobi, Kenya, under the auspices of the Inter Academy Panel, currently known as the Inter-Academy Partnership (IAP). NASAC is a consortium of merit-based science academies in Africa and aspires to make the 'voice of science' heard by policy and decision makers within Africa and worldwide. NASAC is dedicated to enhancing the capacity of existing national science academies and champions the cause for the creation of new academies where none exist.

The membership of NASAC consists of duly established national science academies in Africa that are merit-based, independent, non-governmental, non-political and non-profit scientific organisations. Through its members, NASAC seeks to enhance collaboration and knowledge sharing among scientists by using evidence-based research to African development policy in the domains of social, natural and economic sciences. NASAC aspires to make science academies in Africa vehicles of positive change for science itself, policy and societies. In so doing, academies ensure that science contributes to realising Africa's full potential and sustainable development.

NASAC's overall goals include to enable and inter-connect African science academies to contribute to science, technology and innovation, to make the voice of science heard by African and global decision and policy makers, and to establish a culture of science in the continent.

As an independent consortium of science academies, NASAC continues to unite and strengthen its membership to address challenges on the African continent using scientific knowledge and innovative expertise. Specifically, NASAC has continued to provide advice to regional bodies and organisations on science-related issues of importance to Africa's development through its membership. It has also enhanced the capacity of academies in Africa to improve their role as independent science advisors to governments and to strengthen their national, regional, and international functions. In turn, this has assisted the scientific community in the continent to set up national independent academies or associations of scientists where such bodies do not exist. The main objective being to promote scientific excellence and contribute to creating a culture of science in Africa.

NASAC therefore serves as an authoritative voice of the science community in Africa.

NASAC is only as strong as its members and has remained relevant since its inception by:

- i. Facilitating, through financial or technical support, the formation of science academies in countries where none exist.
- ii. Offering science academies a platform for interaction and collaboration with their counterparts' worldwide.
- iii. Linking scientists and enhance the voice in science through their national academies.
- iv. Strengthening existing academies through provision of capacity building and enhancement of resources. Enhance the operations of academies through provision of training to officials and staff members of their secretariats.
- v. Championing or facilitate the effective networking of science academies by harnessing their collective strengths and to enhance their impact at a continental level.

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ISBN 978-9966-112-00-2

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The Network of African Science Academies
P. O. Box 201
Karen 00502
Nairobi
Kenya

Telephone: +254 0712 914285
+254 0733 297661
E-mail: nasac@nasaonline.org
Web: <http://nasaonline.org/>

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Copy-edited and typeset in Frutiger by The Clyvedon Press Ltd, Cardiff, United Kingdom

Printed by Paperbrand Conqueror Enterprises, Nairobi, Kenya.

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Abbreviations

| | |
|------------|--|
| AASSA | Academies and Societies of Sciences in Asia |
| ARNS | African Regional Nutrition Strategy |
| BMBF | German Federal Ministry of Education and Research |
| CAADP | Comprehensive Africa Agriculture Development Programme |
| CFS | Committee on World Food Security |
| EASAC | European Academies' Science Advisory Council |
| FAO | Food and Agriculture Organization of the United Nations |
| FNSA | Food, security, nutrition and agriculture in Africa |
| GDP | Gross domestic product |
| HLPE | High-Level Panel of Experts on Food Security and Nutrition |
| IANAS | InterAmerican Network of Academies of Sciences |
| IAP | The InterAcademy Partnership |
| ICT | Information and communication technology |
| NAFSIP | National Agriculture and Food Security Investment Plan |
| NASAC | Network of African Science Academies |
| ReSAKSS | Regional Strategic Agriculture Knowledge Support System |
| SAKSS | Strategic Agriculture Knowledge Support System |
| SDG | Sustainable Development Goal |
| SMART | Specific, measurable, achievable, relevant, and time-bound |
| STI | Science, technology and innovation |
| STISA-2024 | Science, Technology and Innovation Strategy for Africa - 2024 |
| UN | United Nations |
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| UNICEF | United Nations International Children's Emergency Fund |
| WHO | World Health Organization |

Foreword

The InterAcademy Partnership (IAP) global network of the world's science academies brings together established regional networks of academies, forming a new collaboration to ensure that the voice of science is heard in addressing societal priorities.

Combating malnutrition in its various forms—undernutrition and micronutrient deficiencies as well as overweight and obesity—is a problem that is faced by all countries. The transformation of agricultural production towards sustainability is a global issue, connected with the global challenges of poverty reduction, employment and urbanisation. International academies of science have a substantial history of interest in these areas, for example as indicated by the InterAcademy Council publication in 2004 *“Realizing the promise and potential of African agriculture”*. Science has the potential to find sustainable solutions to challenges facing the global and national food systems relating to health, nutrition, agriculture, climate change, ecology and human behaviour. Science can also play a role in partnering to address important policy priorities such as competition with land use for other purposes, for example energy production, urbanisation and industrialisation with environmental connections for resource use and biodiversity. The Sustainable Development Goals adopted by the United Nations in 2015 provide a critically important policy framework for understanding and meeting the challenges but require fresh engagement by science to resolve the complexities of evidence-based policies and programmes.

There is an urgent need to build critical mass in research and innovation and to mobilise that resource in advising policymakers and other stakeholders. Academies of science worldwide are committed to engaging widely to strengthen the evidence base for enhanced food and nutrition security at global, regional and national levels. In our collective Academy work, we aim to facilitate learning between regions and to show how academies of science can contribute to sharing and implementing good practice in clarifying controversial issues, developing and communicating the evidence base, and informing the choice of policy options. The current IAP initiative is innovative in bringing together regional perspectives, drawing on the best science.

In this project, we utilise the convening, evidence gathering, and analytical and advisory functions of academies to explore the manifold ways to increase food and nutrition security and to identify promising research agendas for the science communities and investment opportunities for science policy. A core part of this work is to ascertain how research within and across multiple disciplines can contribute to resolving the issues at the science–policy interface, such as

evaluating and strengthening agriculture–nutrition–health linkages. Food systems are in transition and in our project design we have employed an integrative food systems approach to encompass, variously, all of the steps involved, from growing through to processing, transporting, trading, purchasing, consuming, and disposing of or recycling food waste.

Four parallel regional academy network working groups were constituted: in Africa (the Network of African Science Academies, NASAC); the Americas (the Inter-American Network of Academies of Sciences, IANAS); Asia (the Association of Academies and Societies of Sciences in Asia, AASSA); and Europe (the European Academies' Science Advisory Council, EASAC). Each had an ambitious mandate to analyse current circumstances and future projections, to share evidence, to clarify controversial points and to identify knowledge gaps.

Advice on options for policy and practice at the national–regional levels was proffered to make the best use of the resources available. Each working group consisted of experts from across the region who were nominated by IAP member academies and selected to provide an appropriate balance of experience and scientific expertise. The project was novel regarding its regionally based format and its commitment to catalyse continuing interaction between and within the regions, to share learning and to support the implementation of good practice.

These four regional groups worked in parallel and proceeded from a common starting point represented by the agreed IAP template of principal themes. Among the main topics to be examined were the science opportunities associated with the following:

- Ensuring sustainable food production (land and sea), sustainable diets and sustainable communities, including issues for agricultural transformation in the face of increasing competition for land use.
- Promoting healthy food systems and increasing the focus on nutrition, with multiple implications for diet quality, vulnerable groups, and informed choice.
- Identifying the means to promote resilience, including resilience in ecosystems and in international markets.
- Responding to, and preparing for, climate change and other environmental and social change.

Each regional group had the responsibility to decide the relative proportion of effort to be expended on different

themes and on the various elements of the needs and experience.

All four networks are now publishing their regional outputs as part of their mechanism for engaging with policymakers and stakeholders at the regional and national levels. Also, these individual outputs will be used as a collective resource to inform the preparation of a fifth, worldwide analysis report by the IAP. This fifth report will advise on inter-regional matters, local-global connectivities and those issues at the science-policy interface that should be considered by inter-governmental institutions and other bodies with international roles and responsibilities. We intend that the IAP project will be distinctive and will add value to the large body of work already undertaken by many other groups. This distinctiveness will be pursued by capitalising on what has already been achieved in the regional work and by proceeding to explore the basis for differences in regional evaluations and conclusions. We will continue to gather insight from the integration of the wide spectrum of scientific disciplines and country/regional contexts.

This project was formulated to stimulate the four regional networks in diverse analysis and synthesis according to their own experience, traditions and established policy priorities, while, at the same time, conforming to shared academy standards for clear linkage to the evidence available. The project as a whole and in its regional parts was also underpinned by necessary quality assessment and control, particularly through peer review procedures.

We anticipated that the regions might identify different solutions to common problems—we regard the generation of this heterogeneity as a strength of the novel design of the project. We have not been disappointed in this expectation of diversity. Although the regional outputs vary in approach, content and

format, all four provide highly valuable assessments. They are customised according to the particular regional circumstances but with an appreciation of the international contexts and are all capable of being mapped on to the initial IAP template. This last IAP collective phase of mapping, coordination and re-analysis is now starting. According to our interim assessment, the project is making good progress towards achieving its twin objectives of (1) catalysing national-regional discussions and action and (2) informing global analysis and decision-making.

We welcome feedback on all of our regional outputs and on how best to engage with others in broadening the discussion and testing our recommendations. We also invite feedback to explore which priorities should now be emphasised at the global level, what points have been omitted but should not have been, and how new directions could be pursued.

We take this opportunity to thank the many scientific experts, including young scientists, who have contributed their time, effort and enthusiasm in our regional working groups, which have done so much to help this ambitious project to fulfill its promise to be innovative and distinctive. We thank our peer reviewers for their insight and support, and all our academies and their regional networks and our core secretariat for their sustained commitment to this IAP work. We also express our gratitude for the generous project funding provided by the German Federal Ministry of Education and Research (BMBF).

Krishan Lal
Co-chair, IAP for Science

Volker ter Meulen
Co-chair, IAP for Science
and President, IAP

October 2017

Summary

National academies of science have a long tradition of engaging widely in strengthening the evidence base to underpin the delivery of enhanced food and nutrition security at regional and national levels. NASAC, the Network of African Science Academies, has developed this report for audiences in Africa as a contribution to the project worldwide initiated by IAP, the InterAcademy Partnership, the global network of science academies. The IAP work brings together regional perspectives in parallel from Africa, Asia, the Americas and Europe on the opportunities for the science–policy interface, identifying how research can contribute to resolving challenges for agriculture, food systems and nutrition. The messages are aimed at national policymakers, member academies, the scientific community and other stakeholders in Africa.

This NASAC report evaluates the current context of food and nutrition security and agriculture in the light of continental and international commitments by African leaders and governments. We recognise that these targets will not be met without transformation of agriculture and food systems.

Science, technology and innovation (STI) offer many opportunities for addressing the main constraints to embracing transformation in Africa. Many existing, new and emerging technologies could support the diversification of African agriculture and food systems, to:

1. increase the efficiency of policies, programmes and the monitoring and evaluation,
2. increase the efficiency of agricultural systems amidst increasing uncertainties,
3. increase the efficiency of food systems and their ability to make more safe and nutritious foods available to all year-round, and
4. improve human nutrition, health and productivity to break the intergenerational cycle of poverty and deprivation.

Without significant investment in building human capacity and infrastructure for STI research, training and extension the necessary transformation of African agriculture and food systems will not occur. This report takes an integrated approach to understanding the complexities and inter-relationships of agriculture and food systems in the African context and the influence these have on rural livelihoods and the diets of households and vulnerable individuals. We, therefore, focus on the opportunities that STI offers to overcome these challenges and to transform African food systems

to achieve the “Africa we want” as set out in the vision of Agenda 2063.

This report identifies many opportunities to generate, connect and use research. The following priorities are highlighted as illustrations of how scientific enquiry can generate information for evidence-based policy, advance and support transformation of the African agricultural sector and food system to improve food security and reduce malnutrition in Africa.

Strong political commitment informed by scientific evidence

- Achieving Africa’s ambitious growth and development agenda as set out in Agenda 2063 and the Malabo Declarations will require well-informed policies and action plans, appropriate institutional arrangements, capacity at all levels and the requisite funding. This will necessitate strong investment from African governments and their funding partners along with active partnership of the private sector and international research centres.
- Governments should take responsibility for directing this transformation and provide opportunities for closer engagement between researchers and policymakers for mutual learning and benefit.
- Strategic cooperation in the form of research alliances and partnerships could include the establishment of multi-sectoral and multi-institutional STI platforms as part of national food and nutrition systems for peer review, mutual learning, and mutual accountability in line with Malabo Declaration commitments to improve policy and programme alignment, harmonisation, and coordination. Multi-sectoral institutional platforms and arrangements can mitigate the challenges of low investment, brain-drain, brain-wastage as well as the fragmented and expensive duplication of efforts.
- Closely monitoring land use change and determining its impacts on food security at different levels – national, community and household – is necessary to protect household food security and ensure that these investments do not degrade the natural environment and that they lead to inclusive economic growth and viable employment opportunities—especially for women and youth.
- Advancing information and communication technology (ICT) to support multi-sectoral “big data” platforms with the necessary capacity could

support ongoing monitoring and evaluation of policies and programmes as well as the efficiency of the agriculture and food systems. This will inform policies and actions, and document the impact of these for mutual learning and refinement of development actions.

Agriculture and food system efficiency

- Ensuring quality and sustainable supplies of seed and vegetative propagation materials of indigenous and underutilised foods will increase production of these foods, making them more available to consumers. National research systems must support these actions. More investment is necessary to collect and categorise orphan crops and wild populations. Modern molecular breeding technologies offer potential to preserve these resources and increase their availability.
- Researching how to improve the efficiency of livestock and aquaculture rearing and feed quality is equally important for food and nutrition security in Africa.
- Advances in appropriate modern technologies, biotechnology and biosciences can provide timely and efficient management of biotic and abiotic factors that limit agricultural productivity and nutrition.
- Applying modern breeding technologies could improve and enhance the diversity and utilisation of indigenous and underutilised foods in Africa.
- Researching to find solutions that reduce the drudgery in Africa's largely unmechanised farming and food systems can improve equality. This is essential for freeing up women's time in particular.

Farming system resilience

- Improving mixed farming systems could improve food productivity amidst greater levels of uncertainty. This could improve prospects for smallholder livelihoods and environmental protection.
- Stakeholders (including farmers) need to work together to improve the resilience of farm systems through climate-smart agriculture approaches. These require supportive public policies and context-appropriate programmes supported by research and development, well-qualified extension staff as well as knowledge and technology transfer on a large scale.
- Monitoring changes in the environment through soil and water mapping can support agricultural production decisions at all levels. Getting this

information into the hands of African farmers via ICT applications to support decision making is essential.

Food system efficiency, human health and well-being

- STI research can find ways to promote product diversification with nutritious foods; processing to extend shelf life and make healthy foods easier to prepare, and improved storage and preservation to retain nutritional value; ensure food safety; extend seasonal availability and reduce post-harvest losses (including aflatoxin) and food waste. These solutions should consider current changes in demand, predict future demand changes and shape the future of the African food system in ways that will provide nutritious food for all.
- Develop processing and packaging technologies to respond to consumer demands for safe and healthy alternative foods and extend the shelf life of foods. The limitations of water and power supplies need to be considered in developing these technologies.
- Increasing funding for more research into the fortification, biofortification and enrichment of foods can increase the nutritional value of commonly consumed foods, improve the bioavailability of nutrients for absorption and metabolism or decrease the concentration of anti-nutrient compounds that inhibit the absorption of nutrients (for example phytates and oxalates). A focus on harnessing the inherent properties of indigenous knowledge and foods is needed.

Food safety and waste reduction

- Developing technologies to overcome the shortage of cold storage and refrigeration in Africa is necessary, including innovation in processing and packaging to ensure stable, safe foods, particularly in areas where electrification levels are low. The use of solar energy is one possible area to explore.
- Strengthening and enforcing agriculture and food regulations and standards, and building the requisite capacity (human, technological and infrastructure), will ensure food safety and ensure access to export markets.
- Research and training can reduce the risks and hazards associated with the over-use of agricultural chemicals.
- Alternative approaches and techniques can reduce the need for chemicals that are harmful to the environment, and human health and well-being, yet are affordable and accessible to farm households in Africa.

- Empowering farmers to monitor and control the spread of diseases and pests, and enhancing the capacity of farmers with information on digitised soil, weather, cropping and disease information systems to take vital decisions and actions at the farm level.
- Conducting epidemiological research to establish patterns of contamination and health effects of mycotoxins in Africa can inform better management and containment of these risks. This needs to be complemented with building more capacity to test and certify products, developing innovative and cheaper testing methods (including rapid digital assessments) and stepping up the enforcement of minimum quality standards in food products through innovative cost-sharing practices.

Human capacity

- Strengthening the human and infrastructural capacity for agricultural research will support

transformation. African academic institutions must work to develop food security and nutrition capacity at all levels of society and across traditional disciplines. Increased effort is required to ensure a well-trained extension service that is constantly updated.

- Providing support and incentives to stakeholders in the agricultural sector to mentor youth involved in value-addition within the context of economic growth, food security and poverty alleviation will assist in addressing unemployment and bringing young people into the sector. Empowering the youth with appropriate skills and mainstreaming gender considerations in food and nutrition security programmes will require deliberate actions on the part of all stakeholders.

1 Introduction

1.1 Global challenges

Global and national food systems¹ present increasing challenges for science communities in tackling issues for agriculture, ecology, health, human behaviour and nutrition and in improving public and private sector research. Academies of science worldwide are committed to engaging in strengthening the evidence base for improving agriculture, food and nutrition security at global, regional and national levels. This NASAC report forms part of a worldwide IAP project. The report seeks to contribute to the broader IAP project objective in facilitating learning between regions and to show how academies can contribute to sharing and implementing good practice on these vitally important topics. The messages on how science can help to resolve critical issues are aimed at the African Union and national policymakers, institutes of higher learning and research institutions in Africa, the wider science community and other stakeholders.

The major global challenges for delivering food and nutrition security are compounded by the pressures of a growing global population (projected to reach over 9 billion by 2050 with 70% of the population in urban areas compared with 50% today), climate change, other global environmental changes and economic inequity and instability (Pretty *et al.*, 2010; UNESCO 2010; Government Office of Science 2011). Also, conflict, migration and weak governance lead to famine and starvation. It is, therefore, vitally important to develop agriculture and food systems that are resilient, sustainable and nutrition-sensitive².

The Sustainable Development Goals³ (SDGs) adopted by the United Nations in 2015 (United Nations, 2016) represent a critically important framework for tackling these challenges. However, progressing on the SDGs requires fresh engagement by science – including the economic and social sciences – to address the complexities of evidence-based policies and programmes. The links between food and nutrition security and sustainable development are embedded in multiple SDGs. SDG2 seeks to end hunger, achieve

food security and improved nutrition, and promote sustainable agriculture. SDG1 focuses on poverty alleviation, while SDG3 is aimed at ensuring healthy lives. SDG5 focuses on gender equality, SDG6 on water, SDG7 on energy, SDG 12 on sustainable consumption and production, SDG13 on climate change and SDG15 on land use and management. When building on this close connectivity, there is more to do to ensure that the focus on nutrition is well integrated into pursuit of the SDGs, with specific, quantifiable targets (United Nations, 2014).

Consideration of food and nutrition security must encompass both supply-side and demand-side issues. Reducing waste and changing to healthier consumption patterns will reduce pressure on land and other natural resources. Historically, global production of food has increased faster than consumption, leading to overall reductions in food prices. However, production constraints, together with further increases in demand because of population growth, are exacerbated by changing dietary patterns. Setting priorities for agricultural production⁴ and food security must take account of pressures on other critical resources, particularly water, soil and energy, and the continuing imperative to mitigate and manage the negative impacts of climate change and further loss in ecosystems services and biodiversity.

Achieving food and nutrition security raises important issues for resource efficiency, environmental sustainability, resilience and the public health agenda. Agriculture and the food system account for a significant share of energy consumption and greenhouse gases. According to some estimates, up to one-third of the world's food production is lost or wasted. It is calculated that the food wasted by the EU and North America is equivalent to the total food production of Sub-Saharan Africa (Steering Committee of the EU Scientific Programme for Expo, 2015). Therefore, there is an urgent need for adopting an integrative food systems approach (Government Office of Science, 2011; Steering Committee of the EU Scientific Programme for Expo, 2015).

¹ "A food system consists of all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.), and activities that relate to the production, processing, distribution, preparation and consumption of food, and the outcomes of these activities, namely nutrition and health status, socio-economic growth and equity and environmental sustainability" (HLPE, 2014).

² Nutrition-specific programmes address specific deficiencies directly through the provision of food or nutrients, while nutrition-sensitive programmes address nutrition more directly, increasing the supply and availability of affordable, nutritious foods.

³ Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development, 1987).

⁴ When we discuss agriculture in this report, we refer to the broad definition of agricultural activities including field crops, horticulture, livestock, fisheries and forestry for food produced by smallholders and through commercial production and include urban and peri-urban production as well as processing activities across these value chains. The report draws attention to the rich diversity of domesticated, semi-domesticated and edible food resources in Africa.

1.2 Improving the evidence on food and nutrition security

Our future challenge is to provide the world's growing population with a sufficient, sustainable, secure supply of safe, nutritious and affordable, high-quality food produced on less land with lower inputs and in the context of global climate change and declining natural resources. Doing so requires a better understanding of the trade-offs between different policy actions. Tackling this challenge requires new knowledge from the interface of the natural and social sciences as a resource for innovation and for informing policy options across a very broad front.

Achieving food and nutrition security⁵ necessitates addressing the various physical, biological and socio-economic constraints, which limit the ability of people to access a healthy diet year-round (Quentin *et al.*, 2015). Even in the developed world, hunger is linked to poverty, a situation where there are inadequate resources to obtain food. While food insecurity is experienced at national, community and household level, malnutrition is experienced at an individual level. Although food security is one foundational requirement for nutrition, two other elements are essential for sound nutrition: care and healthy environments. Food security is achieved when households can access (through production or purchasing) enough safe food to meet their daily nutritional requirements. Food security includes four foundational elements: availability, access, nutrition (termed utilisation in the original definition), and stability of supply (or resilience). People experience food insecurity when they are uncertain about their future supply of and access to food, when their intake (of energy as well as macro- and micronutrients) is inadequate for a healthy life, or when they are obliged to resort to socially unacceptable means of acquiring food (Hendriks, 2015). In these situations of food insecurity, hunger and malnutrition are possible, although not necessary, consequences (Frongillo, 2013). Nutrition security requires adequate food, hygiene, health and social care.

Scientific knowledge is a global public good, provided by a wide range of research institutions, supported by a wide range of funders. As discussed in detail elsewhere (for example von Braun and Kalkuhl 2015; Steering Committee of the EU Scientific Programme for Expo,

2015), collective engagement is essential to clarify the knowledge gaps and priorities and to improve policy and science interaction. Enhancing the science–policy interface for food and nutrition security requires improving efforts to reflect the diversity of international science insights. It also requires exchange and coordination between disciplines and individual research efforts to promote transparency in synthesis, assessment of new knowledge and to increase the legitimacy of recommendations to governments and society (von Braun and Kalkuhl, 2015).

1.3 Food insecurity and malnutrition are detrimental to African development

Food insecurity and malnutrition are forms of deprivation, which manifest in a variety of symptoms of varying severity (Hendriks, 2015). Food insecurity is not a single experience, but a sequence of stages reflecting increasing deprivation of basic food needs, accompanied increasingly constrained household resources (Hendriks 2015). It is a continuum of experiences ranging from the most severe form, starvation, to complete food security, defined as a state in which all the criteria of the Food and Agriculture Organization of the United Nations (FAO, 1996) definition of food security are met, and there is no worry about future food supply to meet these criteria (Hendriks, 2015).

Hunger and wasting⁶ are extreme experiences of food insecurity, but food insecurity can also manifest as “hidden hunger”⁷ or less observable forms of malnutrition. However, hunger and undernutrition are not the only possible consequences of food insecurity. Malnutrition includes undernutrition, micronutrient deficiencies as well as overweight and obesity. Overweight and obesity are the result of unbalanced intakes and, in particular, the consumption of too many calories without necessarily having a regular intake of adequate protein and micronutrients and modern lifestyles that lack regular physical activity.

Since 1995, there has been considerable debate about the link between food insecurity and obesity. Until recently, overweight was inevitably blamed on excessive food intake. However, poverty and food insecurity are both forms of material deprivation that have a range of harmful consequences that could well include excess weight gain (Frongillo, 2013).

⁵ The Rome Declaration on Nutrition (FAO and WHO, 2014) set out the three key forms of malnutrition as (1) hunger and undernutrition, (2) micronutrient deficiencies, and (3) overweight and obesity. For decades, the focus of food security and nutrition policies in Africa has been exclusively on undernutrition, yet there is increasing awareness of the significant problem that micronutrient deficiencies play in human productivity and development. In addition, although typically deemed to be a problem associated with the west and affluence, increasing numbers of people of overweight and obese people are reported in Africa—especially in urban settings and often in the same households as undernourished children. The causes are associated with calorie-dense, nutrient-poor diets.

⁶ Low weight for age.

⁷ Micronutrient deficiencies.

Many factors affect the nutrition status of a population. These include agricultural production, consumption patterns, feeding practices for infants and young children, gender, food safety health, water and sanitation (Covic and Hendriks, 2016). While the evidence in support of investment in nutrition has existed in health and nutrition circles for a very long time, the need for integrating nutrition objectives and deliberately considering nutrition in agriculture and development programmes has only recently become topical. There is compelling evidence that shows that not addressing nutrition comes at a significant cost to both households and national budgets. These costs are associated with treating the health-related consequences of undernutrition, micronutrient deficiencies as well as overweight and obesity and non-communicable diseases such as diabetes, high blood pressure and cardiovascular diseases (Covic and Hendriks, 2016). There is evidence to show that the national prevalence of child stunting⁸ from malnutrition is proportional to gross domestic product (GDP) (Ruel and Alderman, 2013). Malnutrition also presents lost opportunity costs. Improved nutrition can make a significant contribution to overcoming underdevelopment—about health and well-being as well as increased economic growth and development (Covic and Hendriks, 2016).

It is not yet fully understood what makes a healthy and sustainable diet and how it can be produced and accessed. But we do know that improving global and African food systems requires action throughout the system: in reducing risk, managing demand, reducing waste, improving governance as well as producing more food (Dogliotti *et al.*, 2014). Every country is to a greater or lesser degree co-dependent on local production and global trade. Understanding this interconnectedness between local and global systems directs attention to a wide range of issues related to trade networks, land use and climate change. The necessary actions will include implementation of diverse policy initiatives and transition to a new economic system in which a central issue is the internalising of current externalities, for example allocating economic value to environmental impacts of food systems (Ehrlich and Herte, 2016).

As part of the wider considerations for local–global interconnectedness in food systems, future food production must be achieved with a lower impact on the environment (German *et al.*, 2016), and more efficient use of inputs and land. Careful consideration will be necessary to take into account the implications of sustainable intensification on biodiversity and ecosystem services as well as the impact on the

availability of affordable food of good nutritional quality and animal welfare (Godfray and Garnett, 2014). Adopting an integrated approach to addressing the challenges of the future is essential to tackle cross-cutting issues and identify opportunities for cross-disciplinary investigation without losing the essential science focus.

1.4 The situation of food and nutrition security in Africa

To realise the commitments of African governments, the implementation of comprehensive national food security and nutrition strategies and plans is essential. Doing so requires a review of currently fragmented policy contexts, the design of comprehensive national plans that focus and step up the implementation of coordinated actions, establishment of institutions to coordinate strategic actions and the close monitoring and evaluation of the outcomes and impacts of these plans. To deliver on international (i.e. SDG), continental and national development goals, these plans need to be ambitious and aligned to broader development agendas, while their targets need to be specific, measurable, achievable, relevant and time-bound (SMART). Strategic guidance is needed on how to leverage the momentum and commitment of the SDGs to gain traction on the Malabo/CAADP (Comprehensive Africa Agriculture Development Programme) agenda and vice versa. This includes aligning the SDG targets at the national level with delivering on the Malabo commitment targets.

Although remarkable progress has been made during the past two decades in reducing extreme hunger in Africa (Malabo Montpellier Panel, 2017), population growth, demographic changes and urbanisation are placing pressure on food systems to increase yields and make more food available, as well as to produce more diverse and nutritious foods to address all forms of malnutrition (Malabo Montpellier Panel, 2017). Climate change, conflict and protracted crises could contribute to an increase in hunger and child malnutrition that could reverse the gains achieved over the past two decades and jeopardise progress towards achieving the nutrition goals of the Malabo Declaration, the African Union Commission's Agenda 2063 and the SDGs.

This is an important moment for shaping the region's future and ensuring that the much-needed agriculture-led growth and development can simultaneously deliver on improving nutrition and health, saving lives, improving the productivity of Africa's population and curbing public health expenditure on nutrition-related diseases. This includes addressing not only the

⁸ Being short for their age.

usual elements of undernutrition but also widespread micronutrient deficiencies (termed “hidden hunger”) and the growing problem of overweight and obesity that is increasing across the African continent.

Most food policies in Africa focus on addressing undernutrition (stunting, wasting, underweight and key micronutrient deficiencies such as iodine, iron, vitamin A and zinc) (Lokosang *et al.*, 2016). Few pay attention to the growing problem of overweight and obesity now associated with developing economies (Steyn and Mchiza, 2014; International Food Policy Research Institute, 2016). Current predications are that Africa will require radical actions to reduce undernutrition, correct micronutrient deficiencies and simultaneously stem the tide of increasing overweight and obesity. Each of these three problem areas must be addressed by making Africa’s food system deliver healthier, more nutritious foods and making these foods more available and affordable to all people.

The over-reliance of many African countries on imports to meet the local demand for staple foods, in particular, makes these economies vulnerable to many risks, insecurities and uncertainties. While importing staple food is not negative *per se*, disproportional reliance on external sources for food is a risk that threatens long-term resilience. At the household level, food insecurity leads to the adoption of precautionary strategies (such as reducing consumption) that compromise the sustainability of households, their livelihoods as well as the nutrition of individuals.

Food security is essential to achieve sound nutrition and to ensure overall peace and stability. Three current famine zones in Africa (northeastern Nigeria, Somalia and some counties of south Sudan) demonstrate the complexity of food security in Africa. These famines are not the result of a single shock (the onset of conflict or a food shortage) but the resultant failure of long-term development processes (Gross and Webb, 2006). The recent famines have been initiated by conflict that disrupts food production, blocks the flow of food and humanitarian aid, and drives food prices beyond the level of affordability.

1.5 IAP and NASAC

The IAP is the global network of more than 130 science academies aiming to harness the power, authority and credibility of its member academies and to access their combined scientific talent. Recent structural changes have resulted in a newly integrated organisation by merging what was the InterAcademy Panel together with the InterAcademy Medical Panel and InterAcademy Council.

Science academies have a tradition of taking responsibility in ensuring that the collective voice of science is heard in major policy debates. By engaging with its four regional academy networks (for Africa, the Americas, Asia and Europe), IAP now can advise on the science dimensions of policymaking at the global level and across disciplines. Many member academies and the regional academy networks have previously conducted studies in areas relevant to food and nutrition security. In November 2014, the IAP Executive Committee agreed that this was a vitally important topic in which to pioneer a new series of IAP projects, with food and nutrition security as one theme.

The IAP project is producing four regional reports together with a global synthesis that highlights the similarities and differences between the regions, explores inter-regional issues, and provides advice and recommendations for implementation at global, regional and national levels, customised according to local circumstances and strategic needs. Thus, this IAP activity combines twin goals of delivering strong consensus messages at the global level, with clarification of the scientific basis of current disparities in policy expectations, objectives and options in the different regions of the world. The IAP project was initiated with a meeting at the German National Academy of Sciences Leopoldina in June 2015, bringing together experts to advise where work by IAP and its regional academy networks might add value to the considerable volume of work already conducted by many other scientists in seeking to inform policymakers. Collective discussion following this initial step helped to develop a common, agreed template to inform and guide all four regional Working Groups (summarised in Box 1 with further details elaborated

Box 1

This report offers an updated perspective on the InterAcademy Council’s 2004 report on “*Realizing the Promise and Potential of African Agriculture*”, which set out recommendations and proposed approaches and key actions required to deploy science and technology to more effectively improve agricultural productivity and food security in Africa (InterAcademy Council, 2004). The 2004 report was commissioned by the United Nations Secretary-General, Kofi Annan. This updated report by NASAC takes on board new challenges and opportunities in agriculture, food security and nutrition that are relevant to achieving the Malabo and SDG commitments. It seeks to identify the opportunities for African countries to address current food and nutrition security problems and take proactive steps to harness the potential of agriculture and food systems to ensure future food and nutrition security through the application of STI solutions.

NASAC has significant previous experience in working on areas relevant to the present project and some of our work is briefly summarised in Appendix 2. NASAC constituted an expert Working Group formed from member academy nominations and other invited experts (Appendix 3) to identify and clarify the critical issues for Africa within the overall project defined by the IAP.

in Appendix 1). Necessary components of this shared template are to understand regional characteristics, to delineate the significant opportunities and challenges where science can help to inform policymaking and serve as a resource for innovation, to address the impact of the cross-cutting determinants of the various priorities, and to advise on how to mobilise scientific resource. This report, by the Network of African Science Academies, contributes the perspective of Africa on the topic.

1.6 Objectives and scope of this NASAC report

The ambitions in producing this report were to explore and clarify where there is consensus on key questions and to advise where further assessment of the issues is required with particular regard to (1) facilitating the translation of scientific advances into applications for societal benefit and into informing the choice of policy options and (2) identifying where there are particular scientific opportunities for inter- and trans-disciplinary research throughout food systems, building on the strengths in individual disciplines. We highlight the importance of basic research in helping to characterise new frontiers in science and of the long-term commitment to research that is often required (for example to assess new crops or other innovation). The report also acknowledges and discusses the continuing roles of academies in clarifying and auditing the achievements of research (including the objectives of enhanced cooperation and reduction of unnecessary competition); building an enduring scientific capacity to deliver; engaging with other national and international organisations and assessing inter-country and inter-regional issues.

The issues are complex and inter-connected. There is a myriad of policy issues on the table for the attention of policymakers at any one time. It is a challenge for policymakers to keep up to date with a diverse range of new policy insights and developments in the international arena amidst very strong competing agendas for their time (and budgets) (Hendriks, 2015). Apart from conducting and communicating the findings of basic, applied and blue-sky research, academies can play an important role in simplifying, streamlining and focusing attention on core policy decisions, developing the capacity to implement and evaluate progress on such policies and support governments in achieving the SDGs, Agenda 2063 and the targets of the Malabo Declarations (African Union, 2014a).

Sound policymaking requires (1) two-way communication between policymakers and the merit-based research community and (2) readily accessible, up-to-date evidence for decision making. Policymaking systems in some African countries lack both these elements. This report seeks to provide guidance on how science and scientific research can support and advance food security and nutrition by providing focused, prioritised action options for African governments to consider implementing with the support of the Academies of science and science communities across the continent. The key messages and recommendations in this report are for consideration by the African Union and national policymakers, member academies, others in the science community and the broader stakeholders, including the private sector. This report is timely, providing insight and options for African governments to consider in the revision of their priorities and plan of action to achieve the SDGs and Malabo commitments.

2 Food and nutrition security in Africa

While the number of people affected by malnutrition is difficult to calculate – because a person can suffer from more than one type of malnutrition simultaneously – the scale of malnutrition in Africa is staggering (see Box 2). The burdens regarding human suffering, mortality and disease are large (International Food Policy Research Institute, 2016), but so too are the economic burdens (African Union *et al.*, 2014).

Recognising the extent and consequences of the burdens, African leaders have committed to improving nutritional status, in particular the elimination of child undernutrition in Africa to bring down stunting to 10% and underweight to 5% by 2025 (African Union, 2014c). Also, African leaders have signed up to the World Health Assembly Targets to reach key targets for six nutrition outcomes by 2025. They have also signed up to the SDGs, the second of which is to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture”. The World Health Assembly targets have been adopted by the Africa Regional Nutrition Strategy (WHO, 2014b) and as part of the United Nations General Assembly Decade of Action on Nutrition 2016–2025 (United Nations General Assembly, 2014). African governments have also endorsed the Rome Declaration on Nutrition and Framework for Action adopted by the Second International Conference (ICN2) in November 2014.

Tables 1 and 2 present data from the 2017 Global Nutrition Report for the proportion of children stunted and wasted ranked by prevalence rates. The Global Nutrition Report assessed whether countries would attain the World Health Assembly nutrition targets

by comparing the required reduction rate with the country’s recent performance in reducing rates. The 2017 Global Nutrition Report contains data compiled from secondary sources including the United Nations Children’s Fund (UNICEF), World Health Organization (WHO) and the World Bank among many others. If the current rate of reduction is greater than or equal to the required rate, then the country is “on course” (shaded in green in Tables 1 and 2). If the current reduction rate is higher than zero but less than the required rate, then the country is designated as “off course but making progress” (shaded in yellow), and if the current reduction rate is less than or equal to zero (i.e. stunting rates are static or increasing), then the country is designated as “off course, no progress” (shaded in red). The cells shaded in grey in Tables 3 and 4 indicate that no data were available to determine progress towards the goals.

As with many other regions, the nutrition problems in Africa are multiple and overlapping. Figure 1 shows that eight of the 54 African countries (Botswana, Egypt, Equatorial Guinea, Lesotho, Libya, Namibia, South Africa and Swaziland) are facing serious public health issues about stunting, women’s anaemia and overweight and obesity—a triple burden. Thirteen countries are facing a double burden of undernutrition and overweight and obesity. Only four countries are facing serious single burdens of stunting (Ethiopia and Rwanda) and women’s anaemia (Ghana and Senegal). In Burundi, Chad, Djibouti, the Democratic Republic of the Congo, Ethiopia, Guinea-Bissau, Niger and Somalia the percentage of children under 5 years of age who are not stunted or wasted ranges between 43% and 48% (Haddad *et al.*, 2016).

Box 2 Current rates of malnutrition in Africa

- 58 million children under age 5 are too short for their age (stunted), 13.9 million weigh too little for their height (wasted), and 10.3 million are overweight. None of these children are growing healthily (UNICEF, WHO and World Bank Group, 2015).
- 163.6 million children and women of reproductive age are anaemic (WHO, 2015a).
- 220 million people are estimated to be calorie deficient (FAO, 2015a).
- 8% of adults over 20 are obese (WHO, 2015b).
- Adult obesity is on the rise in all 54 African countries (2010–2014) (WHO, 2015c).
- 13 countries in Africa have to manage serious levels of stunting in children under five years or anaemia in women of reproductive age and adult overweight (Haddad *et al.*, 2016).

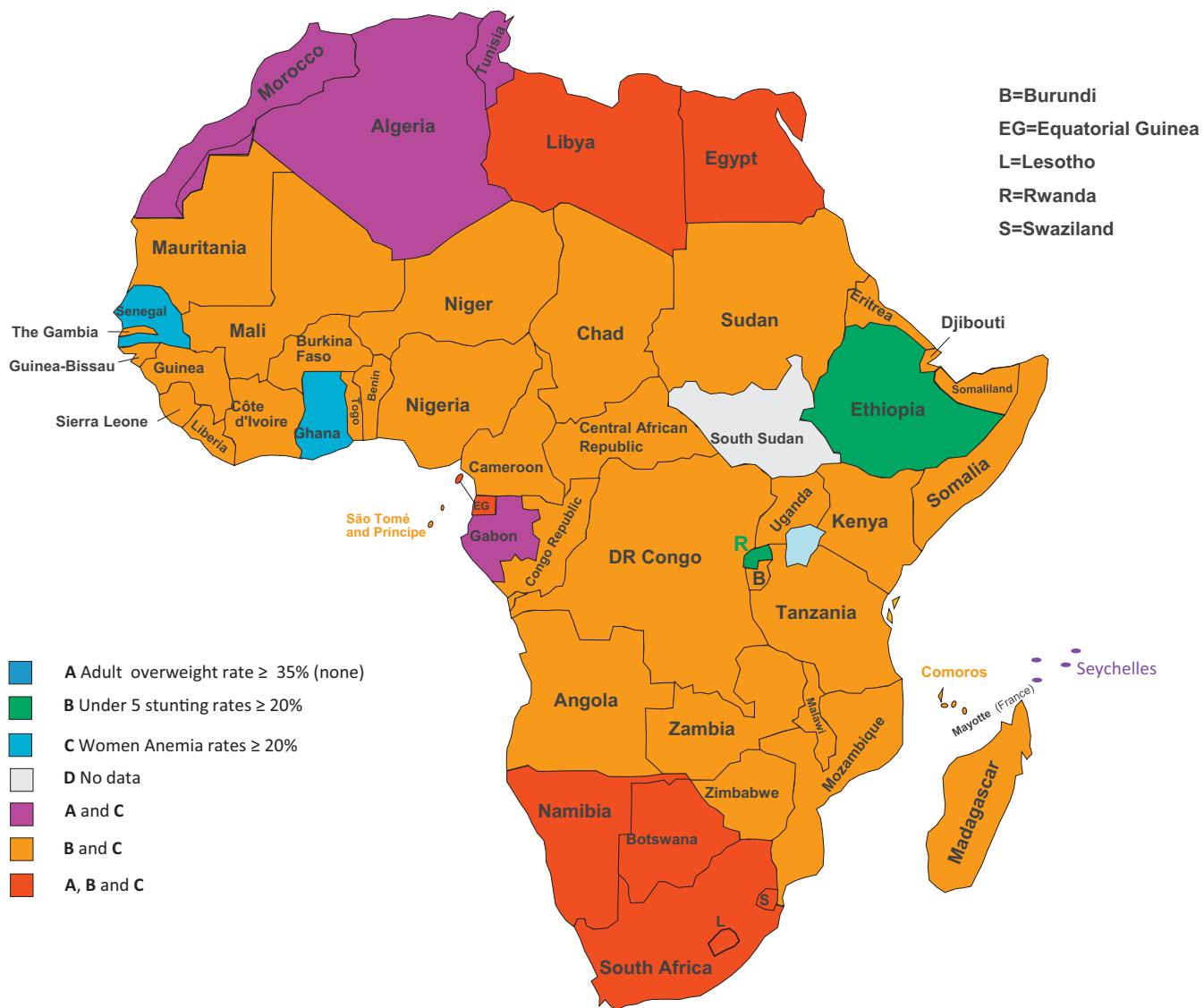


Figure 1 The multiple burdens of malnutrition in African countries (adapted from Haddad et al., 2016).

Table 1 Which countries are on course to meet the World Health Assembly stunting target?

| Rank | Country | % stunted |
|------|--------------------------------------|-----------|
| 1 | Seychelles | 8 |
| 2 | Tunisia | 10 |
| 3 | Algeria | 12 |
| 4 | Morocco | 15 |
| 5 | Sao Tome and Principe | 17 |
| 6 | Gabon | 18 |
| 7 | Ghana | 19 |
| 8 | Senegal | 21 |
| 9 | Libya | 21 |
| 10 | Congo (Republic of the) | 21 |
| 11 | Egypt | 22 |
| 12 | Namibia | 23 |
| 13 | South Africa | 24 |
| 14 | The Gambia | 25 |
| 15 | Somalia | 25 |
| 16 | Swaziland | 26 |
| 17 | Kenya | 26 |
| 18 | Equatorial Guinea | 26 |
| 19 | Guinea-Bissau | 27 |
| 20 | Burkina Faso | 27 |
| 21 | Togo | 28 |
| 22 | Zimbabwe | 28 |
| 23 | Mauritania | 28 |
| 24 | South Sudan | 31 |
| 25 | Guinea | 31 |
| 26 | Botswana | 31 |
| 27 | Cameroon | 32 |
| 28 | Comoros | 32 |
| 29 | Liberia | 32 |
| 30 | Nigeria | 33 |
| 31 | Lesotho | 33 |
| 32 | Djibouti | 34 |
| 33 | Benin | 34 |
| 34 | Uganda | 34 |
| 35 | The United Republic of Tanzania | 34 |
| 36 | Angola | 38 |
| 37 | Rwanda | 38 |
| 38 | Sierra Leone | 38 |
| 39 | Sudan | 38 |
| 40 | Ethiopia | 38 |
| 41 | Mali | 39 |
| 42 | Chad | 40 |
| 43 | Zambia | 40 |
| 44 | The central African Republic | 41 |
| 45 | Malawi | 42 |
| 46 | The Democratic Republic of the Congo | 43 |
| 47 | Niger | 43 |
| 48 | Mozambique | 43 |
| 49 | Madagascar | 49 |
| 50 | Eritrea | 50 |
| 51 | Burundi | 58 |

Table 2 Which countries are on course to meet the World Health Assembly wasting target?

| Rank | Country | % wasted |
|------|--------------------------------------|----------|
| 1 | Rwanda | 2 |
| 2 | Swaziland | 2 |
| 3 | Morocco | 2 |
| 4 | Lesotho | 3 |
| 5 | Zimbabwe | 3 |
| 6 | Equatorial Guinea | 3 |
| 7 | Gabon | 3 |
| 8 | Tunisia | 3 |
| 9 | Sao Tome and Principe | 4 |
| 10 | Kenya | 4 |
| 11 | Uganda | 4 |
| 12 | Malawi | 4 |
| 13 | Algeria | 4 |
| 14 | Seychelles | 4 |
| 15 | Ghana | 5 |
| 16 | Cameroon | 5 |
| 17 | The United Republic of Tanzania | 5 |
| 18 | Angola | 5 |
| 19 | Benin | 5 |
| 20 | South Africa | 5 |
| 21 | Guinea-Bissau | 6 |
| 22 | Mozambique | 6 |
| 23 | Liberia | 6 |
| 24 | Burundi | 6 |
| 25 | Zambia | 6 |
| 26 | Nigeria | 7 |
| 27 | Togo | 7 |
| 28 | The central African Republic | 7 |
| 29 | Botswana | 7 |
| 30 | Namibia | 7 |
| 31 | Libya | 7 |
| 32 | Senegal | 8 |
| 33 | Burkina Faso | 8 |
| 34 | The Democratic Republic of the Congo | 8 |
| 35 | Congo (Republic of the) | 8 |
| 36 | Sierra Leone | 9 |
| 37 | Ethiopia | 10 |
| 38 | Egypt | 10 |
| 39 | Guinea | 10 |
| 40 | The Gambia | 11 |
| 41 | Comoros | 11 |
| 42 | Chad | 13 |
| 43 | Mauritania | 15 |
| 44 | Eritrea | 15 |
| 45 | Madagascar | 15 |
| 46 | Mali | 15 |
| 47 | Somalia | 15 |
| 48 | Sudan | 16 |
| 49 | Niger | 19 |
| 50 | Djibouti | 22 |
| 51 | South Sudan | 22 |

3 Science and policy context: overview of the food security and nutrition policy context in Africa

Numerous statements, decisions and declarations commit Africa's leaders to realising the continent's aspiration for equitable growth and socio-economic development through improving food security and human nutrition. The African Union's Agenda 2063 (African Union, 2015a) is the policy framework for the Continent's development over the next 50 years (2014–2063) and was reiterated in three declarations promulgated at the African Union Heads of State and Government meeting in Malabo in 2014 (African Union, 2014a).

Agenda 2063 prioritises healthy and well-nourished African citizens as an overarching goal for realising a "prosperous Africa that is based on inclusive growth and sustainable development" (African Union, 2015a, p. 2). In January 2014, African leaders adopted the Common Africa Position on the post-2015 development agenda with six priority areas for development and implementation of the SDGs in a manner that adequately supports the broader development of the continent (African Union, 2014b). These priority areas include striving for "inclusive economic growth that reduces inequality and ensures sustainable agriculture, food self-sufficiency and nutrition security for all" (African Union, 2014b). The Malabo Declaration on accelerated agricultural growth and transformation for shared prosperity and improved livelihoods (African Union, 2014c) reaffirms the Maputo commitment of African governments to allocate at least 10% of their national budget to agriculture and to seek to achieve an annual agricultural growth rate of at least 6% as per the CAADP. The Declaration deliberately commits to using agricultural growth for eradicating undernutrition (stunting and underweight), rather than leaving achievement of this goal solely to the health sector as in the past. A biennial review process has been initiated by the African Union to ensure accountability for making progress on the Malabo commitments. Heads of state and governments will have to report on progress, starting at their January 2018 summit.

The Malabo Declarations (African Union, 2014a) recognise and call for investment in social protection (with a special focus on women and youth) and agribusiness programmes as integral elements of national investment plans. The CAADP Post-Malabo Implementation Strategy and Roadmap (African Union, undated) emphasises implementing agriculture-based activities that have direct links to nutrition, particularly

through stabilisation of food availability and prices and diversification of available nutritious foods for local consumption for improving the diversity of diets (Lokosang *et al.*, 2016).

3.1 CAADP as a framework for development

CAADP was initiated through the Maputo Declaration on Agriculture and Food Security in Africa (African Union, 2003) and sought to achieve Millennium Development Goal one to halve the levels of extreme poverty and hunger by 2015 (United Nations, 2015). CAADP provides an overarching policy framework for attaining food security, nutrition and sustainable development through agriculture-led investment at national and regional levels within Africa. It is an unparalleled framework for agricultural transformation that has raised the political profile of agriculture and investments in the sector (Badiane *et al.*, 2016). CAADP has been particularly successful in raising the profile of agriculture and reclaiming African ownership and leadership of the strategic agenda in the agricultural sector through national investment planning. CAADP initiated a transition to evidence-based planning and implementation and thereby increased the technical credibility of the agenda itself at the global level and national agricultural strategies and programmes at country level (Badiane *et al.*, 2011).

Each CAADP component was guided by a framework for action. Following the guidance of the Global Plan of Action (High Level Task Force on the Global Food Security Crisis, 2010), and drawing inspiration from Millennium Development Goal one, the CAADP Framework for African Food Security⁹ guided countries on the design of their national plans to address structural, systemic and long-term aspects of chronic food insecurity challenges on the continent. The framework was developed as a deliberate attempt to ensure that the CAADP agricultural growth agenda targeted the chronically poor and vulnerable directly, instead of hoping for a trickle-down effect (African Union and New Partnership for Africa's Development, 2009). The Framework for African Food Security was launched at a meeting of 16 African governments at the height of the 2007–2008 world food crisis.

Four specific strategic intervention areas were identified as the crucial barriers to improving Africa's food security and nutrition status as set out in the CAADP

⁹ AU/NEPAD (African Union/New Partnership for Africa's Development), 2009. The Comprehensive Africa Agriculture Development Plan Framework for African Food Security. NEPAD: MidRand. <https://www.microlinks.org/sites/microlinks/files/group/resource/files/CAE999~1.PDF>

Framework for African Food Security. These are as follows:

- Improved risk management at the household, community, national and regional levels to inform decisions that ultimately build and protect assets and investments, and to strengthen national, regional and community responses to climatic and economic shocks that risk and undermine the coping mechanisms of vulnerable populations.
- Increased supply of affordable commodities through production and improved market linkages to make more food available and affordable to households and communities. Strategies to increase the production of staple commodities are also more likely to affect poor smallholder farms, increasing their incomes and extending the geographical reach of markets to underserved areas.
- Increased economic opportunities for the vulnerable for the diversification of livelihoods, particularly through adding value to agricultural production (local processing, handling, transport, etc.) to build resiliency and contribute to rural growth. Close coordination with strategies undertaken under other pillars will improve outcomes under this objective, as will proactive attempts to link safety-net programmes capable of providing opportunities for the poor to accumulate, diversify and invest in assets.
- Increased quality of diets through diversification of food among target groups. While investment in increasing the production of staple foods will have an immediate and significant impact on the poor, increasing the ability of the poor to access sufficient protein and micronutrients through varied, nutritious diets is necessary to ensure sustainable gains in the battle against poverty, hunger and malnutrition.

The framework included attention to the right to food for all Africa's citizens, specifically focusing on the more vulnerable groups of society, those chronically affected by hunger and malnourishment, with particular attention to women and children in addressing both long- and short-term effects (African Union and New Partnership for Africa's Development, 2009).

It is essential for food and nutrition security policy at the regional and global levels to be integrated across areas in a multi-sectoral approach and for there to be policy integration at the different levels of governance within and between countries (Holzapfel and James, 2016). While many first-generation CAADP programmes (2009–2015) included food security and nutrition programmes and activities, nutrition was not as well integrated into them. Systems for assessing the impact

of these interventions on nutrition of specifically vulnerable groups were not always included in monitoring and evaluation (Covic and Hendriks, 2016). Nutrition indicators have now been incorporated in the CAADP Results Framework (African Union and New Partnership for Africa's Development, 2009) and will be included in the monitoring of CAADP implementation progress.

Currently, the CAADP process is entering a second stage in which countries will review their first-generation CAADP National Agriculture and Food Security Investment Plans (NAFSIPs), and design and implement second-generation NAFSIPs. This is an opportune moment for academies to rally behind national governments in providing the technical expertise and relevant evidence-based inputs to shape these investment plans.

3.2 The African regional nutrition strategy

CAADP has been instrumental in bringing about increased food production on the continent. However, it is also widely accepted that the increased food production has not resulted in the same levels of reduction in undernutrition that would be expected (Lokosang *et al.*, 2016). Therefore, some nutrition policies and frameworks at the continental, regional and national levels were formulated to reinforce the framework. This includes the African Regional Nutrition Strategy (ARNS) (African Union, 2015b), which includes specific nutrition targets aligned to World Health Assembly nutrition targets (Lokosang *et al.*, 2016). The ARNS 2016–2025 sets out concrete evidence-based interventions that are consistent with the globally agreed Comprehensive Implementation Plan for Maternal, Infant and Young Child Nutrition that was adopted at the 2012 World Health Assembly (WHO, 2014a) and by the 23rd African Union Ordinary Session through the Malabo Declaration on ending preventable child and maternal deaths in Africa (African Union, 2014d). The ARNS spells out four strategic areas to guide the African Union and Member States in the governance of nutrition. These include the definition of standards, norms, policies and frameworks for African Union Member State adoption and ratification.

The African Union Agenda 2063, the African Union 2014–2017 Strategic Plan and the Malabo Declaration on accelerated agricultural growth and transformation for shared prosperity and improved livelihoods articulate the continental commitment to achieving SDG2. Two further Malabo Declarations on (1) nutrition security for inclusive economic growth and sustainable development in Africa (African Union, 2014d) and (2) ending preventable child and maternal deaths in Africa (African Union, 2014e) reinforce the commitment to improving nutrition. Other African Union Commission initiatives support this commitment, including the

CAADP Nutrition Initiative and the CAADP Nutrition Capacity Development Initiative launched in 2011. Also, 37 African countries are involved in Scaling-Up Nutrition programmes (Scaling Up Nutrition Movement, 2016).

3.3 Science, technology and innovation strategy for Africa

The African Union Science, Technology and Innovation Strategy for Africa (STISA) was adopted in June 2014, at the 23rd Ordinary Session of African Union Heads of State and Government Summit (African Union, 2014f). The strategy is part of "Agenda 2063, which is underpinned by science, technology and innovation as multi-function tools and enablers for achieving continental development goals" (Ikounga 2015, p. 8). The strategy calls for the diversification of sources of growth and sustenance of Africa's current economic performance, and, in the long run, lifting large sections of our population out of poverty (African Union, 2014f). "It is envisaged that the collaborative and coordinated implementation of the identified priority areas is a prerequisite to building an integrated and prosperous Africa, where citizens are assured of equal access to quality nutrition, healthcare and education and skills training, efficient and cost-effective communications, peace and security, and sustainable management of natural resources and environments to secure the interests of future generations" (African Union, 2014f, p. 21).

The strategy is based on six priority areas that contribute to the achievement of the African Union Agenda 2063 Vision. The first priority is notably the eradication of hunger and achieving food security. In this regard, the strategy recognises that "Africa must build its response capacities and capabilities and leverage existing relationships with relevant partners outside Africa, to

deal with emerging challenges, such as low commodity yields, climate change and variability, water and land management, and increasing price volatility in global markets which could undermine efforts to eradicate hunger and achieve food and nutrition security. Processing, conservation and distribution of agricultural products go far beyond the framework of rural and agricultural development sectors and requires a concerted intervention of STI" (African Union, 2014f, p. 22).

Priority two, namely the prevention and control of diseases, recognises that "millions of Africans die of communicable and non-communicable diseases that are preventable and treatable as a result of weak and fragmented health systems; inadequate resourcing to scale proven interventions; limited access to health services and technologies (particularly in rural areas); poor human resources management; and extreme poverty. Substantial improvements in healthcare delivery are necessary for African economic and social development" (African Union, 2014f, p. 22).

The strategy further recognises that leveraging STI for sustainable socio-economic development will require a multi-disciplinary approach incorporating social sciences, humanities and natural sciences. Over the past 50 years, global long-term growth and poverty reduction have been driven by increases in productivity, which in turn are determined by the pace of technical change (Badiane and Collins, 2016). However, Sub-Saharan Africa has considerably lagged behind other regions in this regard. Given the current policy context, it is critical that countries invest in agricultural research to promote technological and institutional innovations to stimulate economy-wide growth and development so as to keep pace with population growth and changing environments.

4 The challenges and opportunities related to food and nutrition security in Africa and STI capacity

The challenges faced in Africa regarding agriculture, food insecurity and malnutrition are unique to the continent. Although much progress has been made in more recent years (the past 15 years), the rate of reduction of hunger and undernourishment has been uneven and not enough to achieve continental and international targets (Malabo Montpellier Panel, 2017). Africa's population growth rate is higher than for other regions, while productivity rates are the lowest. Rural infrastructure is weak and less developed than other regions. The majority of the poor depend on agriculture for their livelihoods, but market access and institutions are weak. The number of trained agricultural scientists is lower than in other regions. However, the core challenges facing Africa include food availability, food access and affordability, and stability and resilience of food systems. This chapter sets out the core challenges facing Africa regarding food and nutrition security and agriculture.

4.1 The food availability situation in Africa

The most severe food insecurity is typically associated with natural and civil disasters. Although recent episodes of severe food insecurity in Southern Africa, in particular, were attributed to severe drought and unpredictable weather, many African famines are not only the result of shocks such as the onset of conflict or a severe production failure but partly a consequence of inadequate developmental policies and processes failure. Current assessments of the food supply¹⁰ in Africa reflect the fragile state of food security at the national and continental levels.

Food security assessments by FAO (2016a) at the end of 2016 indicated that 39 countries globally are in need of external food assistance. Twenty-nine of these are in Africa. The number of countries and proportion of people affected by food shortages across the continent, as well as the need for food imports to meet domestic demand, are a cause for concern. The recent drought induced by El Niño resulted in a 15% drop in regional cereal production from 29 million tonnes in 2015 to 26 million tonnes in 2016—approximately 11% lower than the 5-year average. Approximately 40.8 million people (22.5% of the rural population) were predicted to face severe food insecurity until March 2017 (FAO, 2016b). The shortfalls indicate the dire situation that shocks can produce when national food systems are weak and lack resilience, raising the need for national

action to build up reserves and build long-term resilience amidst uncertainty.

Urgent action is needed at national level to establish a prioritised plan of action and the necessary budgetary resources to alleviate these shortages and build better resilience in domestic food systems. This is primarily achieved through increasing food production, improving food system efficiency and establishing systems for mitigating and managing food shortages. Such policies need to consider that some factors including population growth, urbanisation and changing production patterns will affect future food supplies. At current cereal consumption levels, Africa already depends on substantial imports.

4.2 Effect of population growth and urbanisation on food availability

It is estimated that by 2050 Africa's population will increase 2.5-fold and the demand for cereals is likely to triple (van Ittersuma *et al.*, 2016). The region's rapid population growth is attributed to rising life expectancy and declines in death rates, particularly of children (Jayne and Ameyaw, 2016). This will have consequences for agriculture and food systems (see Box 3).

There is a slow decline in fertility, but fertility rates have remained high, and 62% of Africa's population is below the age of 25 years (Jayne and Ameyaw, 2016). Africa is the only region of the world where the population of under-15s is continuing to grow (Jayne and Ameyaw, 2016). The population below the age of 24 accounts for the largest share of the population in

Box 3

Rapid population growth in Africa will have important consequences for agriculture and food systems:

- Rapid population growth will put pressure on African food systems to feed its fast-growing cities.
- Land values may rise and the growth of land markets will continue, especially in areas of favourable market access, as people seek land for farming, housing and other non-farm purposes.
- As finite land becomes more populated, agricultural plots become increasingly fragmented and young people may not inherit land, causing migration and demographic and labour market shifts (Jayne and Ameyaw, 2016).

¹⁰ The food availability indicators capture not only the quantity but also the quality and diversity of food. For assessing food availability, several factors are analysed: adequacy of dietary energy supply, share of energy (calories) derived from cereals, roots and tubers, average protein supply, average supply of animal-source proteins and the average value of food production (FAO 2015a).

almost all countries in Sub-Saharan Africa (World Bank and International Fund for Agricultural Development, 2017). The World Bank and the International Fund for Agricultural Development (2017) report that an estimated 440 million young people will enter the rural labour market in Africa by 2030.

The World Bank and the International Fund for Agricultural Development (2017, p. 1) report that “The ‘youth bulge’ is an opportunity for countries to reap a demographic dividend. If the increased number of youth reaching working age can be fully employed in productive and sufficiently rewarding activities in response to market demand, the overall growth and per capita incomes can increase. An appropriate mix of public sector actions will be needed to realise the demographic dividend. If, however, a large share of youth cannot find jobs and earn satisfactory incomes, then the youth bulge can be a potential source of social and political tension, with migration pressures to other countries resulting in a loss of energetic workers with innovative ideas and entrepreneurial potential”. A large share of these youth lives in rural areas, where the demand for rural labour services will be essential to absorbing these new entrants into the workforce and manage the speed of rural to urban transitions. Future labour and land productivity will be influenced by demographic trends, and the needs of youth will need to be factored into future development planning and STI applications (World Bank and International Fund for Agricultural Development, 2017).

4.3 Effect of agricultural, labour and land productivity trends on food availability

A recent Regional Strategic Agriculture Knowledge Support System (ReSAKSS) report (Bahigwa *et al.*, 2016) shows positive trends in agricultural, labour and land productivity in Africa. Agriculture value added in Africa increased remarkably between 1995–2003 and 2003–2008, expanding at an annual average rate of 4.67%, although this was still lower than the CAADP target of 6% per annum (Bahigwa *et al.*, 2016). The rate of growth decreased to 3.35% during 2008–2015. Bahigwa *et al.* (2016) observe that, overall, countries that have been in the CAADP process longest and those that have gone through the key CAADP stages have registered higher growth rates than the countries in the other categories.

Africa’s agricultural production index (2004–2006 = 100) rose from 80.8 in 1995–2003, to 100.4 in 2003–2008, and to 117.2 in 2008–2013 (Bahigwa *et al.*, 2016). These rates were higher in CAADP countries than in non-CAADP countries, with faster growth rates observed in the most recent period.

Labour productivity (measured as agriculture value added per agricultural worker) and land productivity

(measured as agriculture value added per hectare of arable land) have also risen over the past 20 years across Africa (Bahigwa *et al.*, 2016). Labour productivity grew faster during 2003–2008, at 2.11% per year, than during 2008–2015, when it grew by 1.73% per year. The highest labour productivity was recorded in the non-CAADP countries, largely because of higher rates of mechanisation in this group (Bahigwa *et al.*, 2016).

Bahigwa *et al.* (2016) report that land productivity in Africa exhibits trends similar to those of labour productivity, but in this case the countries that had implemented CAADP had higher levels of land productivity than the non-CAADP countries, even though they started at the same annual average of US\$270 in 1995–2003 (Bahigwa *et al.*, 2016).

Cassava yield increased from an annual average 8.6 tons per hectare during 1995–2003 to 9.3 tons per hectare during 2003–2008 (Bahigwa *et al.*, 2016), but declined to 8.4 tons per hectare in 2015. The growth rates of cassava yields were highest during the second period. Yam and maize yields experienced similar trends, growing rapidly during the 2003–2008 period and experiencing declining growth rates during the 2008–2015 period. Meat yield has increased moderately over the past 20 years, with the highest growth rate registered during 2003–2008. Non-CAADP countries have higher meat yields than other categories, perhaps because of more advanced production techniques. Trends in milk yield (kilograms per head) are similar to those of meat yield. Non-CAADP countries produce higher milk volumes per animal than the other categories (Bahigwa *et al.*, 2016).

However, van Ittersum *et al.* (2016) report that recent studies indicate that the global increase in food demand by 2050 can be met through closing the gap between current farm yield and yield potential on existing cropland. However, yield gap closure on the existing production area alone cannot achieve this. Van Ittersum *et al.* (2016) show from a robust yield gap analysis for ten countries in Sub-Saharan Africa (using location-specific data and a spatial upscaling approach) that, in addition to yield gap closure, other more complex and uncertain components of intensification are also needed. These could include increased cropping intensity (the number of crops grown per 12 months on the same field) and sustainable expansion of irrigated production areas (Van Ittersum *et al.*, 2016).

Despite these positive improvements in agricultural production in recent decades, food insecurity and malnutrition are still rife in Africa. This illustrates the point that increasing production alone will not necessarily address food insecurity and malnutrition at the scale necessary to bring about a reduction in the levels of food insecurity and malnutrition. A far broader development approach is needed to ensure

that improvements in agriculture lead to the necessary improvements in food security and nutrition at scale and among those in most need of support. This needs to include issues related to land tenure as well as land and water rights, and institutional reform to manage these resources in responsible ways.

4.4 Food access and affordability

ReSAKSS's (Bahiigwa *et al.*, 2016) Annual Trends Report¹¹ for 2016 shows the power of having a prioritised, funded strategic plan for agriculture and food security. The report demonstrates the impact of the implementation of prioritised national agendas to address critical issues constraining growth and development in Africa. This is illustrated through improvements in poverty, inequality and GDP in Africa. These indicators indirectly reflect improved access to food (Bahiigwa *et al.*, 2016).

The incidence of poverty has been declining in Africa, along with its depth, as measured by the poverty gap index, which declined from 24.7% in 1995–2003 to 17.3% in 2008–2015 (Bahiigwa *et al.*, 2016). Despite a slowdown in GDP per capita growth during 2008–2015, poverty fell faster during this period, at an annual rate of 3.1%, than during 2003–2008, at 2.3% per year. The poverty gap index indicates the resources that would be needed to bring the poor out of extreme poverty.

ReSAKSS reports that Africa has experienced robust economic growth in the past 20 years (Bahiigwa *et al.*, 2016). GDP per capita increased from an annual average of US\$1,438 in 1995–2003 to \$1,690 in 2003–2008, and even higher in 2008–2015, reaching an annual average of \$1,892.32 (Bahiigwa *et al.*, 2016). However, during 2008–2015, growth slowed with GDP growing at less than 1% per year. The slowdown was attributed to broader developments in the global economy, notably the impact of the fuel and financial crises of 2007 and 2008. Countries that signed CAADP compacts early in the process had higher growth rates in GDP per capita during both the 2003–2008 and 2008–2015 periods than those that signed later. These fast growth rates enabled these countries to narrow the gap in per capita income levels with those countries that have not yet adopted the CAADP process. Also, countries that have gone through the key CAADP stages – from signing a CAADP compact, to developing a national agriculture and food security investment plan, to securing external funding sources– those that have progressed the furthest, have registered higher GDP per capita growth rates than those countries that are yet

to go through these key stages (Bahiigwa *et al.*, 2016). Africa's income inequality, measured by the Gini index, has fallen marginally, declining from 44.2 in 1995–2003 to 42.6 in 2008–2015 (Bahiigwa *et al.*, 2016).

Household consumption expenditure per capita is also an indicator of wealth status. This increased substantially from an average of US\$1,015 in 1995–2003 to US\$1,275 in 2008–2015, with the highest annual average growth rate occurring during the 2003–2008 period, consistent with GDP per capita growth patterns in Africa (Bahiigwa *et al.*, 2016). Bahiigwa *et al.* (2016) report that the most advanced countries in the CAADP process registered the fastest improvement in household consumption expenditure per capita.

4.5 Stability and resilience about food security

These first three food security dimensions – availability, access and utilisation (nutrition) – are hierarchical: food availability is necessary but not sufficient for access, and access is necessary but not sufficient for utilisation (Webb *et al.*, 2006). However, all three dimensions depend on stable availability, access to food supplies and the resources to acquire adequate food to meet the nutritional needs of all household members throughout their life cycle. More recent attention to the concept of resilience and the link between short-term shocks and long-term development has aroused widespread interest in how people build resilience to adversity (Barrett and Headey, 2014).

Resilience needs to be considered at all levels of food security. At the continental level, mechanisms are required to ensure responses and coordination of actions in cases where food security and nutrition-related threats extend beyond the control of regional bodies and countries. Examples of such threats could be diseases (human, animal, fish and plant), conflict and migration. Regional policies related to resilience need to pay attention to phytosanitary regulations, food reserve management and emergency responses. Climate change is one issue that affects regional, national and household food security. Climate change and uncertainty are likely to have a profound effect on agriculture and food systems in Africa in the future. Productivity declines due to climate change will have serious implications for food security in Africa. National resilience depends on the mitigation and management of disasters and threats related to agriculture, food security and nutrition. This must include emergency warning systems and monitoring and evaluation of risk related to price, food safety, weather, disease, etc. ReSAKSS reports that, as of August 2016, only 26

¹¹ This report is produced annually and represents the official tracking of Maputo/Malabo commitments on behalf of the African Union. This section of the report therefore draws heavily on this source as an authoritative cross-country comparison developed from national data released by African countries into the international data system.

African countries had food reserves, local purchase for relief programmes, early warning systems and feeding programmes (Bahiigwa *et al.*, 2016). More countries need to pay attention to these measures.

Changes in food security status can be temporary, cyclical, medium-term or long-term. These changes may be caused by sudden reductions in the ability to produce or access enough food to maintain the necessary quantity and quality of dietary intake. Food insecurity is usually seasonal or regular (over periods of a month) but may also be aperiodic, i.e. associated with temporary unemployment, episodes of ill health or other recurring adverse events (Vaitla *et al.*, 2009; Barrett, 2010). Food supply shortfalls lead to major increases in food prices, while increased climate variability would accentuate price volatility (Jayne and Ameyaw, 2016). Since the areas most affected would be those with already high rates of hunger and poverty, food price increases would directly affect millions of low-income people. Among the most vulnerable will be those who depend on agriculture for their livelihood and income, particularly smallholder producers in developing countries (FAO, 2016a). As most Africans' livelihoods and agri-food systems rely on rain-fed farming, Africa is one of the world's most vulnerable regions to climate change (FAO, 2016a).

Understanding these drivers and their impacts on farmers' livelihoods and the environment is essential (FAO, 2015a).

4.6 The strengths and weaknesses of STI in Africa

An assessment of the capacity needs and priorities of STI Policymaking in Africa conducted in the preparation of the Science, Technology and Innovation Strategy for Africa – 2024 (STISA-2024) (African Union, 2014f) found that there is increasing recognition by African leaders and the public of the critical role STI plays in economic growth and human development. Beintema and Stads (2017) report that, in recent years, interest in agriculture by countries and donors has led to increased investment in agriculture for economic growth. This is evident in some influential initiatives and regional and sub-regional processes. Many countries have developed agricultural development and financing plans to strengthen agricultural production and food security as part of CAADP (Beintema and Stads, 2017).

Sub-Saharan Africa's agricultural research spending – including the private and for-profit sectors – increased between 2000 and 2014 (from US\$1.7 billion to US\$2.5 billion purchase parity prices) (Beintema and Stads, 2017). The current level of investment in research and development by Africa as a continent (more than half of which is internationally funded) puts Africa at a strategic disadvantage for STI (African Union, 2014f). Moreover, investment is skewed. Nigeria, South Africa

and Kenya represent more than half of this investment. Likewise, the number of full-time equivalent researchers in agriculture and the related sciences increased by an encouraging 70% in the same period. However, the distribution of research capacity is also skewed. Nigeria, Ethiopia and Kenya accounted for 46% of the agricultural researchers in Sub-Saharan Africa in 2015 (Beintema and Stads, 2017).

Recent African Science and Technology Indicators data (Beintema and Stads, 2017) indicate that agricultural research spending became more dependent on volatile donor funding between 2000 and 2015. Important aspects of STI policy development such as establishing comparable baseline data, and monitoring and evaluation, are not budgeted for (and thus not resourced) in most Member States.

Most national agricultural research systems are relatively small and tend to focus their research on adapting technologies developed elsewhere to meet local needs. Beintema and Stads (2017) report that crop research was the dominant area of African agricultural research in 2014. In this year, 44% of all agricultural researchers from a sample of 36 countries were working on crops, 20% on livestock and 18% on natural resources, with the remaining researchers working on fisheries, forestry or other areas. Country-specific variations are seen, with extensively livestock or island states focusing more attention on these issues. But a remarkable trend is evident, with a focus on production and productivity.

Many Sub-Saharan countries face serious human resource capacity and infrastructure challenges (Beintema and Stads, 2017). The African Union reports that very limited evidence-based policy development takes place in Africa. Most entities responsible for STI policymaking operate in isolation from other policy agencies, with weak links to the private, education and research sectors as well as to African and international policy research think tanks. Many officials involved in or responsible for drafting policy documents do not have the necessary skills or training and have no experience in evidence-based policymaking (African Union, 2014f).

A large cadre of agricultural researchers, especially those qualified to PhD level, are approaching retirement age. This poses a significant risk to the leadership potential for research programmes, the capacity to mentor junior staff and the future ability to produce quality research. Outdated research facilities and equipment also impede researchers and compromise the number and quality of research outputs and impact.

There is no traditional field of study for food security (see Box 4). Moreover, very few programmes globally train nutritionists in food security issues and very seldom is human nutrition integrated into the degree training

Box 4 Food security is transdisciplinary

Food security requires a transdisciplinary approach. Transdisciplinary approaches offer innovative methodologies for high-impact science through understanding and taking action on complex societal problems that cannot be approached and solved by single disciplinary approaches.

of students in agricultural production and extension programmes. The soft skills for transdisciplinary facilitation and engagement are seldom integrated into traditional learning programmes, rendering a significant gap for food security dialogue. These need to be incorporated into the curricula of African universities.

Consequently, no data exist on the human capacity aspect of food security (research or policy) in Africa. African Science and Technology Indicators provides regular reports on agricultural research capacity. The African Capacity Building Foundation's (2012) assessment of agricultural transformation and food security capacity reports that the majority of countries have some capacity to develop a good agricultural strategy, invest in areas to build the skills and provide the innovation needed for the future. Although socio-economists and sociologists are employed by some countries, Beintema and Stads (2017) report that most smaller national agricultural research systems cannot employ the full range of disciplinary experts required to address local challenges.

Likewise, no data currently determine the numbers or competency of the nutrition workforce in Africa (Franzo *et al.*, 2015). Of the 36 countries with the highest burdens of stunting, 21 had major gaps in nutrition training, continuing education and institutional support in 2014 (Geissler, 2015). The continent is highly dependent on external support to fill the human capacity gaps for nutrition programming, evidence generation, and monitoring and evaluation of nutrition.

Jerling *et al.* (2016) state that "Historically, in most academic institutions, nutrition has been 'over-professionalized' with strict curricula to fulfill degree requirements. However, although core science competencies should be maintained, it is also necessary for the training to become responsive to current needs. There is also a need to train a diverse research cadre that includes different disciplines, including those in 'professional' practice, who gain experience and knowledge in practical environment settings". Inadequate academic research output is also indicative of limited capacity in Africa (agricultural, food security and nutrition) (Jerling *et al.*, 2016; Beintema and Stads, 2017). There is a dearth of scientific publications originating from African institutions. The release of new varieties and technologies constrains agricultural development in Africa and reflects poorly on the capacity of agricultural research institutions to actively contribute to relevant STI developments. So too, nutrition research fails to examine key topics in public health nutrition (Aaron *et al.*, 2010; Lachat *et al.*, 2015).

5 Agriculture as a driver of broader development

Agriculture is the main livelihood of much of Africa's population and is an important driver of economic development. Therefore, agriculture can be a powerful lever for raising people's health and nutritional status, while also contributing to other outcomes, such as food security, income, equity and sustainability (Hendriks and Covic, 2016). Agriculture is a source of household income (raised through wages earned by agricultural workers or through the marketed sales of food produced) and expenditure on nutrition-enhancing goods and services (including health, education and social services). Agriculture is known to be a more important source of income for poor and undernourished people in Africa than other economic sectors (Gillespie and Dufour, 2016).

Delivering and promoting the consumption of food that is affordable, safe, of good nutritional quality and available year-round requires working across the food system. As populations become increasingly urbanised and markets more globalised, it is obvious that action is required not only at the level of production, but across the stages of the food value chain—from natural resource management and input supply to production, transport, processing, retailing and consumption (Hendriks and Covic, 2016).

The most direct pathway for improving nutrition is through agricultural production—when production translates directly into consumption (Gillespie and Dufour, 2016). Increasingly, even rural households are relying on purchased staple foods. Urbanisation will also influence dietary patterns and may well lead to nutrition transitions¹² in African cities (Jayne and Ameyaw, 2016). Rapid food system transformation can induce a nutrition transition that will see consumption preferences shifting to include more aspirational than affordable, sugar-laden soft drinks, mass-produced confectionary and fast foods (McIntyre and Hendriks, 2016).

Evidence also shows that food consumption patterns in Africa change as income grows (FAO, 2015a). Diets among the higher-income groups represented by the fifth quintile of the income distribution (Q5) are more diversified than the diets of the low-income group (the first quintile of the income distribution, Q1). The contribution of cereals, roots and tubers to total per capita dietary energy supply decreases whereas that of animal sources, sugar, oils, fruits and vegetables increases significantly as incomes increase (FAO, 2015a). The negative implications of these changes in some circumstances may represent new challenges, which can

be addressed through balanced dietary diversification as well as adequate care practices, health, hygiene and sanitation (FAO, 2015a). These changes lead to more urban-based and consumer-driven demand for foods and lend opportunities for innovation across the food system (Alliance for a Green Revolution in Africa, 2017).

Doing so requires the transformation of agriculture value chains to increase the nutritional value of foods. This change will have multiple benefits for producers and consumers. It will also have a positive influence on the basket of food (such as foods for local consumption rather than export and foods with a relatively high nutritional value) that households produce or can access economically. The nutrient content and food safety (lack of contamination risk) should all be enhanced (Hendriks and Covic, 2016).

We, therefore, need to stimulate the demand for nutritious foods, increasing the demand for and consumption of nutritious food and reducing excessive demand for foods that lead to undesirable health consequences to curb the acceleration of rates of overweight, obesity and non-communicable diseases (Gillespie and Dufour, 2016). Improved nutrition status has benefits for all, including the reduction of premature child mortality and morbidity through improved maternal health.

Not only have African countries recently embarked on agricultural transformation processes, but comprehensive agriculture, food and nutrition policies have started to generate significant overall progress in addressing food insecurity and undernutrition. However, more progress is needed to meet international, continental and country development targets.

Agriculture has the potential to stimulate the kind of inclusive growth needed to lift millions of poor people out of poverty and improve the food security and nutrition situation. If the resource base is more intensively farmed, irrigation potential is exploited and uncultivated land brought into production, the continent could become a net exporter of agricultural products (Alliance for a Green Revolution in Africa, 2017). Significant improvements in land and labour productivity will be necessary to reverse the current widespread reliance on imported staples.

Most agricultural development scholars agree that something dramatic has been happening in Africa for at least the past decade and that until recently it has

¹² A nutrition transition happens when the food environment no longer supports healthy eating and consumers' food choices are limited to high-energy, high-fat food alternatives with severe negative consequences for nutrition and health.

gone relatively unnoticed (Badiane and Makombe, 2015). Agricultural transformation in Africa is leading to tangible impacts on economic growth, poverty reduction and reduction in undernutrition. While much of the progress can be attributed to CAADP, the CAADP programmes in countries are part of a broader economic and social development agenda.

The recent (Alliance for a Green Revolution in Africa, 2017, p. 1) African Agriculture Status Report asserts that “Africa’s recent pattern of growth based on ‘urbanization without industrialization’ has increased rather than reduced the need for an agricultural transformation”. The report argues that “many things are now coming together in ways that give Africa the need, the opportunity, the means, and the ambition to transform its agriculture sector”.

The role of African agricultural transformation is to change current rural poverty into future prosperity by significantly and sustainably increasing the productivity of smallholder farmers (Alliance for a Green Revolution in Africa, 2017). As most farmers are smallholders, and many of these are poor, increases in agricultural output help keep food prices low, reducing poverty (Alliance for a Green Revolution in Africa, 2017). However, ensuring broad-based, inclusive and equitable sustainable economic growth requires careful selection of policy choices. The International Fund for Agricultural Development explains that rural transformation changes the structure of land holdings, technologies, human capabilities and the distribution and dynamics of the population and its labour force (International Fund for Agricultural Development, 2016).

Agri-food system transformation involves a shift from subsistence-oriented and farm-centred systems to more commercialised, productive, and off-farm centred operations (Jayne and Ameyaw, 2016). Jayne and Ameyaw (2016) state that many of these transformation processes have accelerated since 2005 in African countries such as Ghana, Kenya, Zambia, Ethiopia and Rwanda. However, much more is needed and to sustain the gains registered so far, and drive the agricultural transformation needed for Africa’s development to achieve the continent’s Malabo Declaration targets for inclusive growth and the global SDGs. Governments need to take specific policy and programmatic actions to enable and empower rural people to seize the opportunities and address the challenges associated with such transformation (International Fund for Agricultural Development, 2016). This includes policies and supportive STI efforts to ensure food and nutrition security, provide economic and social opportunities for all, protect the ecosystem on which agriculture depends and build resilience to climate change (FAO, 2016a).

The question now is not whether Africa needs an agricultural transformation, but rather what kind of

transformation it needs and how to achieve it. Much of the unprecedented economic growth in Africa between 2005 and 2015 has not led to a shift of agricultural workers from agriculture into urban-based industries as happened after the Green Revolution in Asia (Alliance for a Green Revolution in Africa, 2017). Rather, nearly all non-agricultural growth has been in the services sector—a sector that typically creates low-paid jobs. Modernisation of Africa’s agricultural sector is crucial to create jobs and reduce poverty.

There is, however, currently no consensus on how the agricultural transformation in Africa is best achieved (Alliance for a Green Revolution in Africa, 2017). Some scholars and policymakers view this as possible only through large-scale commercialisation of farming and food systems as seen in developed countries and in South Africa (Alliance for a Green Revolution in Africa, 2017). Evidence shows that this creates little employment growth and can lead to unhealthy dietary changes for consumers. Other scholars and policymakers recognise the dominance of small farms and agricultural businesses in African food systems, and recommend inclusive transformation that promotes the growth of these enterprises, growing through stages of development and providing jobs across the food system (Alliance for a Green Revolution in Africa, 2017; World Bank and International Fund for Agricultural Development, 2017).

Future directions and requirements for food security in Africa will need to focus on governance and coordination of policies, food system transformation, production and uncertainty, food environments, and health and nutrition. The following sections provide insight into the elements that will require attention in the next decades in Africa. These lead to a set of key recommendations about the role of STI for food security and nutrition in Africa over the next decades.

Access to land and other productive resources for small and commercialising farmers is vital for inclusive and sustainable development. One element that will need to be considered in the design of transformative policies and strategies in Africa is that land is increasingly threatened by agro-industrial and extractivist expansion, also known as “global land grabbing”. While many of these transfers have the potential to create employment and inject much-needed income into local communities in Africa, there are questions as to whether the business models employed do yield such benefits.

Future research directions in Africa will need to focus on governance and coordination of policies, food system transformation, production and uncertainty, food environments and health and nutrition policy. The following chapters provide insight into these and some of the STI elements that could shape future food systems to improve food security and deliver more

nutritious foods. It is crucial that national STI systems facilitate regular dialogue between policymakers and scientists for mutual exchange of information, knowledge and insights, and shared problem-solving to keep abreast of international and continental priorities, innovations and solutions for adopting and scaling up at the national level. Creating incentives for researchers to focus on these priorities is essential to drive and direct a responsive research system in a country.

Equally important is the need to create incentives for generating blue-sky technology solutions, preferably

in partnership with the private sector. Ensuring competitiveness and inclusiveness will require increased public and private investment in many diverse sectors, including energy, transport, communication, skills development and research (FAO, 2015a). Programmes such as the African Union Research Grant Programme, which is supported by the European Union, could create incentives for closer collaboration between scientists and policymakers, bridging the link between science and policy.

6 Prospects for increasing the efficiency of governance, policies and institutions

Without comprehensive policies and strong institutions to coordinate and manage food security at the national and sub-national levels, governments and states are unlikely to make significant and rapid progress towards the SDGs (Hendriks and Covic, 2016). Food security is a complex concept, requiring a comprehensive policy framework and leadership coordination that creates coherence in policy and actions across multiple sectors and levels (Hendriks and Covic, 2016).

FAO (2015a) reports that there is evidence of a link between improvement in food and nutrition security and national governance effectiveness. The 2016 World Bank estimates of governance indicators show that most countries that have either achieved or made progress towards improving these governance indicators and attaining the Millennium Development Goal targets, and those that achieved one target and made progress in the other, have also improved their performance in controlling corruption and improving government effectiveness (FAO, 2015a)¹³.

While much can be done to improve food and nutrition security through local initiatives and projects, it is most unlikely that a national-scale programme will succeed without strong leadership and visible signals of commitment from the highest levels in government (FAO, 2015b). Food and nutrition security needs to be positioned as a priority at the highest level of governance within an integral element of funded comprehensive growth and development strategies (Hendriks and Covic, 2016).

Governments in Africa could benefit from independent platforms that generate guidance on emerging issues in the global, continental and national food security and nutrition domains. Independent transdisciplinary advisory panels can provide two important functions. First, they can provide an up-to-date and ready source of evidence-based analysis and policy input. Second, such panels could help keep government officials up to date with a diverse range of new policy insights and developments in the international arena amidst very strong competition for their time (and budgets). This is necessary as the concept of food security is iterative and our understanding of its complexities unfolds with increasing insight into the interactions of the multiple causes and the impact of these on the lives of people across the globe.

Some successful international panels provide examples of how experts can assist governments in translating emerging evidence into policymaking inputs and guidance. Some examples include the UN CFS HLPE (United Nations Committee on World Food Security High Level Panel of Experts on Food Security and Nutrition), the Global Panel on Agriculture and Food Systems for Nutrition and the Montpellier Panel (now the Malabo Montpellier Panel). The critical success factors of all three panels come from the independence of their members, their reliance on drawing on expertise from top class experts in the field and sound peer review.

Some successful policy instruments have also emerged since the global crisis, including attempts to establish comprehensive frameworks for national agriculture, food security and nutrition policy that integrate various binding and non-binding international agreements, treaties, conventions and declarations. CAADP is one example of this. Another is the UN CFS Global Strategic Framework, which creates a mirror for the CFS to remind members of current debates and decisions. Documentation of this nature is essential at the continental/regional, national and district levels to ensure coherence and the progressive realisation of commitments and translation of these into strategic objectives.

In their commitment to mutual accountability to actions and results, the Malabo Declarations (African Union, 2014a) call for alignment, harmonisation and coordination among multi-sectoral efforts and multi-institutional platforms for peer review, mutual learning and mutual accountability (Bahiigwa *et al.*, 2016). Bahiigwa *et al.* (2016) report that, in 2015, only 17 African countries had inclusive, institutionalised mechanisms for mutual accountability and peer review, mostly in Western Africa. Six countries were implementing evidence-informed policies with adequate human resources in place. Fifteen countries had functional multi-sectoral and multi-stakeholder coordination bodies—mainly agricultural sector working groups, primarily in Western Africa. Only five countries had successfully undertaken agriculture-related public–private partnerships aimed at boosting specific agricultural value chains. Tanzania and Uganda are the only two countries that reported the cumulative value of their public–private partnerships, at US\$3.2 billion and US\$156 million, respectively (Bahiigwa *et al.*, 2016).

¹³ In Benin, Cabo Verde, Ethiopia, Ghana, Kenya, Lesotho, Malawi, Mauritius, Rwanda and South Africa, government effectiveness scores in 2013 were far higher than the Sub-Saharan African average, or the scores increased sharply between 1996 and 2013 as in the case of Niger (World Bank and International Fund for Agricultural Development, 2017).

There is an urgent need to strengthen national and regional institutional capacities for knowledge, data generation and management that support evidence-based planning, implementation as well as monitoring and evaluation (Bahiigwa *et al.*, 2016). Therefore, greater 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 and Covic, 2016).

Moreover, evidence-based policy reform requires accurate data to inform planning and programming. Policies at all levels must have SMART¹⁴ targets and key performance indicators that monitor and track performance. Collecting, managing and reporting these data require extensive information systems. Here, information and computing science and the emerging

science of “big data” can play an important role. “Big data” offer opportunities to analyse extremely large datasets to 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 security through innovative approaches and algorithms. Some applications include fraud and risk detection, logistic planning in programmes and price comparisons, as well as predictive and proactive health disease and health management systems. Cloud computing allows for crowdsourcing and the active participation of citizens in mutual accountability systems, as well as in 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.

¹⁴ Specific, measurable, achievable, relevant and time-bound.

7 Prospects for increasing the efficiency of production of agricultural systems amidst uncertainty

FAO (2015a, 2016a) states that it will be difficult, if not impossible, to eradicate global poverty and end hunger without building resilience to climate change in smallholder agriculture through the widespread adoption of sustainable land, water, fisheries and forestry management practices. African farmers face erratic weather and harsh agro-ecologies characterised by low soil fertility, recurrent droughts and/or floods (FAO, 2015a). The region is also affected by extreme climate events such as unusual rainfall and temperature patterns (FAO, 2015a). Plant and animal diseases are also a growing threat to food security in Africa. Conflicts and political instability have compounded existing food and agriculture challenges in several countries. Conflict can disrupt the supply and distribution of inputs and outputs to create price shocks and cause massive displacement of labour (FAO, 2015a).

This section of the report explores opportunities for improving production of agricultural systems through traditional and appropriate technologies, as well as ideas for the application of off-the-shelf high-technology solutions and blue-sky ideas. Increasing the productivity of food systems in Africa in the face of growing uncertainty and instability is a prime research objective to meet future food security. Addressing critical challenges will require an integrated approach that deals with issues pertaining to the sustainable use of natural resources (including water, energy, soils); increasing the productivity of crops and livestock; expanding the number of species used for food production to include neglected indigenous crops; and promoting diversification in livelihood activities¹⁵.

7.1 Sustainable use of natural resources

Competition for land comes from various sources, including urbanisation and the demand for housing, industrialisation, recreation, conservation and foreign investment. Anseeuw *et al.* (2016) report that Africa is the most targeted continent for large-scale land transfers. Not all these acquisitions are dedicated to food production. Many of them are for biofuel production and other crops such as cotton and rubber (Anseeuw *et al.*, 2016). Large-scale land acquisitions mainly target readily accessible, fertile land, in densely populated areas, cultivated by small-scale farmers. In many large-scale land transfer cases, access to water plays an important role (Anseeuw *et al.*, 2016). Such

acquisitions can lead to competition and conflict over land and water use. While many governments and communities initially see these investments as potential sources for development finance, those who are employed are often poorly paid and not consulted or involved in the process (Foundation on Future Farming, 2016). It is also worth noting that large parts of the land acquired are often not used immediately and that the rate of abandoned projects is quite high (Foundation for Future Farming, 2016). Anseeuw *et al.* (2016) report that, in 2016, only 199 of 642 recorded land acquisitions in Africa from 2000 were in production. Such competition raises the importance of careful management of land and water systems to ensure food and nutrition security. Land use change needs to be closely monitored and the impacts of this determined on food security at different levels—national, community and household. Appropriate policies are needed to protect national, community and household food security as national development priorities.

There are many challenges related to water in Africa. Water is needed for food production, food processing and industrialisation as well as for safe drinking water, sanitation and hygiene. The demand for these resources competes for the available water that needs to be eased through use of appropriate technology and policy. Africa's geography leads to unequal water availability (Farolfi and Jamin, 2016). Surface water is not available everywhere in Africa. Beyond the equatorial zone, most water sources are seasonal (Farolfi and Jamin, 2016). Water retention is needed at all levels—from dams to household water capture and storage facilities.

Agriculture currently accounts for 40% of the Earth's land surface and 70% of the world's use of freshwater (UN Water, 2017). The UN predicts that irrigation demands could increase 100% by 2025 (UN Water, 2017). Africa's arid and semi-arid areas use almost all of their available water resources through irrigation of non-groundwater, and many of these countries have to import water to meet their needs (Farolfi and Jamin, 2016). Finding ways to conserve water for all uses is essential to preserve water resources and reduce competition.

Green water is the most important water resource for food production globally and in most African countries, indicating the enormous potential for making green

¹⁵ These recommendations are supported by a recent report by the outcomes of a March 2017 Biotechnology and Biological Sciences Research Council-led workshop on the sustainable intensification of agricultural systems in Sub-Saharan Africa (Biotechnology and Biological Sciences Research Council, 2017).

water more productive in agriculture. Many countries that are currently classified as chronically short of blue water have enough blue plus green water to meet food demand. Some countries that are rich in both blue and green water still suffer from limited access to blue water owing to economic or spatial constraints (water passing through part of the country only). These countries rely heavily on their green water resources. For those on the coast, opportunities can be explored for desalination of seawater. But this technology is still expensive. The resultant waste (high concentrations of salt) pose additional environmental problems. Returning the by-product to the sea would increase the salt levels of the sea and pose further environmental problems. More innovation is needed in recycling wastewater to increase the overall availability of water.

Many countries with large-scale irrigation programmes source water from aquifers, threatening long-term sustainability, which could lead to conflict for water in the future. Large irrigation systems require significant energy to pump and distribute the water. The inter-relationships of water, energy and food are complex. Urbanisation will place increased pressure on the demand for water and compete with water for the production of food. Urbanisation and industrialisation also pose threats to water quality. Many energy-generation systems also depend on water sources for hydroelectric power. Africa has the lowest levels of electrification rates in the world, but the continent also has abundant potential for solar energy (Imbernon 2016).

Production techniques such as hydroponic production with recirculation of water and nutrients in a closed system result in reduced water consumption. For instance, cucumbers and other vegetables grown in greenhouses with closed irrigation systems are reported to consume only 50% of the amount of water used by conventional systems (Marfa, 1999). Moreover, these systems can extend the growing period for year-round production. These systems also allow the containment of plant diseases, particularly viruses, in tropical regions where infestations are a major concern.

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). Technologies for water-harvesting and storage are necessary to support crop and livestock production, particularly in times of water scarcity.

Drip irrigation delivers just the right amount of water, at a specific time to a precise spot from where the water will be best absorbed by the plant. Nineteen African countries have been part of the International Atomic Energy Agency's Technical Cooperation Project, which aims to promote drip irrigation for high-value crops and is anticipated to spread the "more crop per

drop" technology in the farming community across Africa. The International Atomic Energy Agency has been working on the integration of drip irrigation with nuclear technology to effectively quantify water in plant-soil interactions and to avail to all Member States (International Atomic Energy Agency, 2017).

Half of the urban infrastructure that will make up African cities by 2035 has yet to be built (World Bank, 2012 cited by UN-Water, 2017). UN Water (2017) states that "This scenario poses several challenges and, at the same time, offers opportunities to break away from past (inadequate) water management approaches and to shift to innovative water management solutions, such as integrated urban water management, which includes the use of treated wastewater to help meet increasing water demand". Mining, oil and gas, logging and manufacturing all produce wastewater, which is often released into the environment with minimal or no treatment (UN Water, 2017).

Significant investment in technologies and skills to use new technologies are necessary. This includes all areas of water provision and use, including wastewater management and sanitation. Wastewater from agricultural, industrial and sanitation uses pollutes water sources downstream, threatening production of food (including animal and fish production), food safety, polluting drinking water and the environment, and threatening the livelihoods of people who depend on the environment and natural resources. Increasing animal production also competes with water for crops, drinking and sanitation. Contamination of water sources by livestock in rural areas is a major health concern. Protection of water sources is essential for health. Scaling up access to water-using and water-less toilet facilities is also necessary. While technology innovations are needed, education campaigns are also important in changing the perceptions and acceptability of many innovative waterless toilet systems.

7.2 Soil fertility

The Montpellier Panel (2014) reports that declining soil fertility is a major constraint to 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 and Ameyaw, 2016). Tittonnell and Giller (2013) assert that smallholder farmers are largely unable to benefit from current yield gains offered by plant genetic improvement because they farm on depleted soils that are non-responsive to fertiliser application. A holistic and integrated land management strategy is needed, which focuses on raising the organic matter, moisture retention and other forms of soil rehabilitation in addition to greater inorganic fertiliser use as preconditions for sustainable agricultural productivity growth in densely populated

rain-fed farming systems of Africa (Kihara *et al.*, 2016). Comprehensive soil mapping is necessary to address the deficiencies through appropriate soil improvement practices and 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 dissemination of knowledge.

A promising area of research aims to establish the effect that the soil microbiome (the complete genetic content of the microbial communities that live in close association with the plant roots) has on soil and plant health to improve crop productivity. The soil microbiome is known to affect how plants react to environmental stresses such as high salinity and low water availability and to diseases (Nadeem *et al.*, 2014; Spence *et al.*, 2014; Qin *et al.*, 2016). Establishing what proportion of the ability of crops to cope with stresses is due to the activity of the soil microbiome has, therefore, become an important research objective. A mixture of traditional techniques, such as the isolation of microbial strains in the laboratory and modern high-throughput sequencing technologies, are being used to develop full catalogues of the microbial species associated with plants in different soils, including arid and saline ones. One of these initiatives is a large-scale survey of the soil microbiome in ten Sub-Saharan African countries: South Africa, Namibia, Botswana, Zimbabwe, Mozambique, Zambia, Kenya, Ethiopia, Côte d'Ivoire and Nigeria. The expectation is that the project will be expanded to ultimately map the below-ground microbial diversity of the continent (Wild, 2016).

Recognition of the effect of the soil microbiome on plant productivity has also highlighted the need to incorporate the ability to establish beneficial microbiome relations into crop improvement programmes. To date, efforts have neglected this aspect. It is likely that many genetic factors associated with this characteristic have been lost in the process. Development of next-generation crop varieties should simultaneously select beneficial characteristics in the plant and the microbiome, jointly considered as a unit of selection called the "holobiont" (Gopal and Gupta, 2016).

7.3 Facing climate and production risks

The sheer number of smallholder farm families in developing countries justifies a specific focus on the threat posed by climate change to their livelihoods and the urgent need to transform those livelihoods along sustainable pathways (FAO, 2016a). Critical farming decisions also depend on the weather: the amount and distribution of rainfall, the length and the start date of the rainfall season and the timing of dry spells, and there is considerable variation in these parameters throughout the years. Farmers can improve their

resilience through diversification to reduce the impact of climate shocks on income and provide households with a broader range of options when managing future risks (FAO, 2016a).

Overlaying soil and weather information with crop suitability maps can provide hands-on information to farmers and assist in decision making to minimise weather-related production risks. 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 the locally relevant crop, livestock and livelihood options and with the use of participatory tools (Dorward *et al.*, 2015).

Climate-smart agriculture approaches are also needed to improve the resilience of farm systems to the effects of climate change. Widespread adoption of climate-smart agriculture in Africa will require broad adoption by farmers of practices and technologies that promote resilience, and system-wide collective action to promote ex-ante climate risk management activities and ex-post coping strategies. Given the scope and scale of these requirements, leveraging public sector resources is critical (Jayne and Ameyaw, 2016).

7.4 Improving the productivity of farming systems

Improving productivity in the face of uncertainty also requires addressing constraints in mixed farming systems, where the production of crops and rearing of livestock are combined. Two-thirds of the global population and most of the world's poor live in these systems. In addition, most of the meat and milk (60% of the meat and 75% of milk in developing countries) and a significant proportion of key staple crops (41% of maize, 86% of rice, 66% of sorghum and 74% of millet) are produced in mixed farming systems (Herrero *et al.*, 2010). Improving the productivity of mixed farming systems is therefore critical for attaining food and nutrition security. This is also an environmental imperative. 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 ruminant production (Gerber *et al.*, 2013), and for about 39% of the total water used for agriculture. Mixed farming systems are also the largest cause of human influence on the global nitrogen and phosphorus cycles, an important cause of pollution of water resources (Bouwman *et al.*, 2005).

Improving the efficiency of livestock rearing is particularly important in Sub-Saharan Africa, the region of the world with the lowest productivity. Livestock genetic improvement programmes, 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 first step in establishing productive mixed farming systems, and stable national protein sources, is to ensure the feed needed for the livestock is available throughout the year (Rao *et al.*, 2015a). The use of high-quality forage grasses and legumes offers a wide array of benefits. These benefits include improved food security by increasing 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 and the inhibition of nitrification in the soil (the conversion of stable nitrogen in the soil to nitrous oxide, a greenhouse gas 300 times more potent than CO₂) (Rao *et al.*, 2015b).

There are over 600 species of grasses currently used for grazing and as livestock feeds, and most of the grasses used in the tropics originated in Africa (Sandhu *et al.*, 2015). Breeding programmes to improve tropical forage grasses started in the 1960s, several decades after the first efforts to improve temperate pasture species, and are still mostly focused on a small number of species (Sandhu *et al.*, 2015). While several important gene banks of forage species exist – the International Livestock Research Institute holds the biggest collection of African grasses and tropical highland forages¹⁶ – a major obstacle is the lack of funds to accurately characterise and evaluate these collections, a requirement for their use in crop improvement programmes. As a result, the available genetic variability of forage plants is still largely untapped and this resource is largely underutilised (Sandhu *et al.*, 2015). Cultivated forage varieties have mostly been the result of direct selection of individual plants from wild populations and landraces (Sandhu *et al.*, 2015).

Brachiaria grasses, the most widely cultivated forage species in the tropics, originated primarily in natural grasslands in Africa. They were introduced in Central and South America in the 1950s, to increase the profitability of the livestock sector by addressing shortages of feed. In Brazil alone, *Brachiaria* is now planted in over 99 million hectares, equivalent to 85% of the cultivated pastures of the country (Jank *et al.*, 2014). Because *Brachiaria* is adapted to acidic, low-fertility soils and is much more nutritious than the native South American species, forage species, the productivity of grazing animals is increased between five and ten times (Rao, 2014). In monetary terms, *Brachiaria* pastures generate an additional yearly value of about US\$1 billion in Central America, and these grasses are

also credited as having revolutionised the Brazilian beef sector, which generates revenues of US\$50 billion and employs about 7.5 million Brazilians. Brazil is also the biggest exporter of *Brachiaria* seeds, supplying all Latin American countries. This is a lucrative business: about 8 million hectares of pastures need to be restored or replanted each year (Jank *et al.*, 2014).

Despite their enormous contribution to the livestock sector in Latin America, *Brachiaria* grasses are only recently being introduced for commercial cultivation in African countries at a significant scale. So *Brachiaria* is slowly making a comeback to Africa, improved by several decades of plant breeding initiatives in Latin America to increase its nutritious qualities, hardiness and resistance to pests (Maass *et al.*, 2015). A study by the International Centre for Research in Tropical Agriculture (CIAT) estimated that the potential benefits of growing *Brachiaria* for two million smallholder dairy farmers in Kenya, Tanzania, Ethiopia, Uganda, Rwanda and Burundi could be of the order of tens of millions of dollars, with positive knock-on effects for other stakeholders in the value chain (González *et al.*, 2016). Other studies have shown similar results. For example, milk production in cows reared in *Brachiaria* pastures could increase by up to 40% in Kenya and Rwanda compared with native grasslands. Benefits in the coastal areas of Kenya over 20 years were estimated to be of the order of US\$17 million, with consumers benefitting from 30% of these (Simtowe and Ghimire, 2016).

Drought-tolerant *Brachiaria* is also currently being cultivated by more than 30,000 maize smallholder farmers in Kenya, Ethiopia, Tanzania and Uganda as part of the conservation agricultural technology push–pull production system. This system is based on companion cropping to simultaneously control maize stem borer and *Striga* infestations, where it has replaced Napier grass as the “trap” crop for borers (Murage *et al.*, 2015).

Brachiaria reproduces mostly asexually (offspring come from one parent only), which means that the level of genetic diversity is low, and populations consist of clones that are genetically homogeneous; therefore susceptibility to a new pest or disease could potentially wipe out millions of hectares of pastures at once. Since many *Brachiaria* kinds of grass originated in Africa, one important set of initiatives aims to increase the genetic diversity of collections used for plant improvement and conservation (Namazzi *et al.*, 2016; Ondabu *et al.*, 2016). It is also important to evaluate and select suitable varieties for the different ecological zones of African countries, and to establish the most appropriate farming

¹⁶ See <https://www.ilri.org/node/1750>

practices to increase the performance and nutritional quality of the grass, with the participation of farmers in the selection process. Crop improvement programmes will also have to address specific constraints to *Brachiaria* in African settings, such as pests and diseases, and determine suitable management practices (Nzioki *et al.*, 2016). And, last but not least, new cultivars need to be evaluated for their potential for seed production (Gitari *et al.*, 2016).

Improving feed sources in Africa is a key research objective for food and nutrition security and the environmental sustainability of mixed crop production systems. Standard crop breeding objectives include yield (accumulation of leaf dry matter weight), improved nutritional quality and digestibility, resistance to pest and diseases, and an ability to cope with environmental stresses. Improving forage crops presents, however, additional challenges. Since grasses are grown as mixtures in swards, the appropriate combination of forage species needed to sustain nutritionally stable swards throughout the year under different agro-ecological conditions and management systems needs to be determined (Kingston-Smith *et al.*, 2013). Furthermore, this analysis needs to take account of changing weather and climate patterns, which are not fully understood. Characterising the interaction of forage species with livestock is also critical, to determine their response to grazing but also in fulfilling the nutritional requirements of specific animals (Kingston-Smith *et al.*, 2013). These feed sources, which are rich in complex organic matter such as chitin, lignin, cellulose, hemicelluloses and other fibrolytic compounds, are not easily degradable. New advances in science offer opportunities for the development and mass production of microbes and microbial enzymes to enhance the quality and efficiency of feed processing and utilisation. A new promising area of research is the interaction of forage species and livestock feeds with the gut microbiome of livestock, which plays a crucial role in animal digestion and the resulting level of emission of greenhouse gases (O'Callaghan *et al.*, 2016).

In addition to forage crops, food crops such as maize, wheat, sorghum and millet serve dual purposes in Africa: the grain is used as food for humans and their residues as feed for livestock. Smallholder farmers in mixed production systems value the residues as much as the grain, particularly in the dry season. The importance of incorporating characteristics related to the nutritional quality of crop residues in breeding programmes is increasingly being recognised. For example, cowpea varieties grown in Nigeria have been assessed for food fodder characteristics including nitrogen, fibre and energy content, and digestibility. The assessment found high variability for these characteristics and highlighted the need to include forage traits as breeding targets to develop staple crop varieties with increased overall plant

value for mixed crop–livestock systems (Samireddypalle *et al.*, 2017).

Sustainable agricultural practices can significantly improve food security and improve the resilience of food systems. Wide adoption of nitrogen-efficient and heat-tolerant crop varieties, zero-tillage and integrated soil fertility management could boost productivity and farmers' incomes, and help lower food prices (FAO, 2016a). By one estimate, the number of people at risk of undernourishment in developing countries in 2050 could be reduced by more than 120 million through widespread use of nitrogen-efficient crop varieties alone (FAO, 2016a).

Livestock production is central to the economies of most African countries. Meat and milk are not only important protein and micronutrient sources for human diets but also valuable market products. Smallholder farmers produce meat, milk and eggs that are largely marketed and consumed in the country where they are produced. Animals are also important to farm productivity (as labour and as sources of manure) and provide financial security and insurance.

Increases in demand for animal products in African countries outpace supply. Meeting this demand will require substantial increases in production. Key African livestock research targets include increasing the productivity and efficiency of animal food systems and reducing the environmental footprint of livestock production. Livestock rearing in Africa contributes to food security and nutrition by providing subsistence products (meat, milk and eggs, and sometimes blood) and household income. Livestock (including poultry, swine, sheep, goats, cattle and rabbits) are good sources of high-quality animal protein with rich amino acid profiles. While livestock populations have grown tremendously in recent decades, it is expected that demand for livestock products will nearly double by 2050, requiring a concomitant increase in production to meet per capita demand for poultry meat, red meat, milk and eggs in particular.

Poultry, swine and small ruminants are fed waste products, while larger ruminants graze on shrubs and trees. Balanced rations are needed for efficient feed utilisation and livestock productivity. In commercial production, feed represents the largest proportion of the cost of production (FAO, 2005). For poultry and swine, this can be as high as 70% of the total cost of production.

To reduce feed costs, reliance on imported feed ingredients must be avoided; and to promote self-reliance, indigenous feed resources can be incorporated into feeds. A wide variety of locally sourced ingredients exist that can increase food supply without sacrificing feed efficiency; they have good nutritional values and provide excellent sources of carbohydrates, proteins, fats

and other nutrients (minerals and vitamins). Available feed resources of local origin include cereals, legume seeds, pasture species and alternative feedstuffs such as unexploited and underutilised forest trees and shrubs. However, some sources contain anti-nutritional factors which may limit their utilisation, particularly in non-ruminants. Detoxification improves the quality of such feedstuffs.

Emerging challenges in animal health include improving resistance to disease and combating the misuse of antibiotics in animal production systems, which is known to be linked to the development of antimicrobial resistance in important human as well as animal pathogens. An example of such pests is the trypanosome parasites. In Africa, these parasites are transmitted by tsetse flies and cause a wasting disease commonly known as 'sleeping sickness' in people and 'nagana' in livestock. The latter disease, formally known as African animal trypanosomiasis, greatly restricts cattle rearing in 32 countries of Sub-Saharan Africa and remains a major constraint to rural development and poverty alleviation. The annual economic losses due to lost animals and animal products are estimated to be between US\$1 billion and US\$6 billion (Yaro *et al.*, 2016). This makes the eradication of trypanosomiasis a key research target for Africa.

Trypanosomiasis in livestock can be controlled by keeping the population of tsetse flies low through, for example, the use of insecticides, but these can pose environmental risks and are difficult to administer. The animal disease can also be controlled by treating livestock with trypanocidal drugs, but these are prohibitively expensive for many African farmers and can lead to the development of drug resistance in parasite populations. Development of conventional vaccines against the parasite has been thwarted by the ability of trypanosomes to continuously change the antigenic properties of their surface coat and thus evade attack by the host's immune system (Radwanska *et al.*, 2008). Finally, efforts to increase the tolerance of commercial cattle breeds to trypanosome infection through conventional breeding with native African cattle able to tolerate infection with trypanosomes have been made problematic by the many genes involved in controlling the disease resistance trait (Hanotte *et al.*, 2003).

The discovery that innate resistance to trypanosomiasis in some African wild animals is linked to the presence of a protein in their blood that kills trypanosomes, called APOL1, has opened new avenues of research. Mice transgenic for a synthetic APOL1 gene are fully resistant to infection by trypanosomes (del Pilar Molina-Portela *et al.*, 2005). Efforts to determine whether the APOL1 protein also confers resistance to cattle are underway, as one of several possible strategies to eradicate this devastating disease.

Environmental protection is essential for preserving the production potential of agriculture in Africa. Combining social protection with conservation programmes is one way of simultaneously generating responsible farming practices and allowing for environmental regeneration. An example of the successful integration of social protection into environmental conservation efforts comes from the seasonal fishing closure in Rodrigues. This small island is located 650 kilometres off the coast of Mauritius. The island derives most of its income from fishing and agriculture. One traditional female livelihood is catching octopus. Traditionally this involves the use of spears to extract the octopus from its natural habitat in burrows in coral reefs. While some of the catch is consumed on the island, most are exported to Mauritius. Increasing unemployment, the ease of carrying out this activity and disinterest in other agricultural activities have led to an increasing number of participants. Overexploitation of this resource, damage to the natural habitat and catching of juvenile females led to a steady decline of the landings, from 780 tons in 1994 to 270 tons in 2010. It was predicted that the octopus population could be depleted by 2015.

In 2012, the government of Rodrigues, supported by non-governmental organisations, passed legislation to close the fishing season over the breeding season, from 13 August to 12 October annually. A sensitisation campaign was taken to schools, fishers and community centres, broadcast widely on radio and backed with the distribution of free advocacy T-shirts. During the closed period, registered fishers were channeled into alternative environmental protection public works activities, as a form of compensation. This involved the planting of mangroves along designated parts of the coast, beach and riverbeds; cleaning of reservoirs; control of invasive plant species and surveillance against poaching.

In the first 19 days following the reopening of the fishing season in 2012, the catch amounted to 190 tons or two-thirds of the annual catch in 2011. This increase is largely attributed to an increase in the size of 1,725 grams of the average octopus compared with the previous year. Moreover, the percentage of undersized females decreased from 90.2% of females landed in October 2008 to 10.71% in October 2012. After continual decreases over the previous 15 years, annual landings for 2012 (570.7 tons) are almost back to their level in 2003 (580.2 tons). The closure scheme now has improved enforcement against poaching and illegal trade. During the season 2016–2017, an additional 2 months' closure was implemented in February to ensure the growth of juveniles to maturity in the lagoon.

Given the success of the programme, Mauritius and Zanzibar implemented the programme in 2016 with comparable results. Several countries including Mozambique, Zanzibar, Tanzania, Kenya, Seychelles

and Uganda have shown interest in implementing the model.

Adaptation through sustainable intensification and agricultural diversification may have to be combined with the creation of off-farm opportunities, both locally and through strengthened rural-urban linkages (FAO, 2015a). Financial support (microfinance, credit, subsidies, loans, insurance, etc.) plays an important role in risk reduction for producers. ICT applications and advances in digital banking offer opportunities for solving some of these constraints.

7.5 Optimising the utilisation of indigenous crops, livestock, fish and underutilised foods

The world derives 60% of its food energy from three crop species, wheat, rice and maize, while over 7,000 species are underutilised, neglected and held in low esteem. Many highly nutritious African indigenous crops are threatened with extinction. African countries are endowed with a rich diversity of indigenous food crops, described as superfoods. African indigenous food crops have economic and nutrition potential and necessary agronomic traits to ensure resilience against climate change. However, poor seed quality has been a major hindrance to optimising the production of these plants.

There is a need to collect and categorise these underutilised crops and wild populations of important plant species and combine these with modern molecular breeding technologies. These gene pools have the potential to generate strains with higher nutritional value, increased resistance to pests and increased yields with lower inputs, as well as expand the food items by diversifying food resources to mitigate the current and upcoming climatic impacts. Also, there is a need to apply modern molecular breeding technologies to improve their agronomic traits. Research on the wild relatives of cultivated species has the potential to enlarge the gene pool that can be used in breeding programmes to develop more nutritious and pest- and disease-resilient crops.

Research is needed on the domestication of indigenous crops. The lack of seed, poor seed quality and unaffordability of quality inputs are constraints and risks to farmers. Much of the seed in Africa is distributed through informal arrangements that lack assurance systems that affect production and yields. Increasing the availability of affordable and diverse quality seeds is essential to manage risk and improve nutrition. Seed regulatory systems should be strengthened regarding regulations, facilities and human capacity. For root crops and vegetative propagated crops such as cassava and banana, scaling up the availability of plant material through tissue culture can increase production of diverse varieties and protect genetic diversity. Research is also needed to develop protective seed coatings to protect

plants from soil-borne pests and pathogens while also providing micro bio-fertilisers.

Many indigenous African livestock, fish and plant breeds are resilient to many risks and adverse growing conditions but are viewed as famine foods, foraged and turned to by the poor in adverse situations. There is an urgent need to create pride and demand for these foods and for investment in research and technology development across the food system to integrate these resources into the daily food basket of African communities. *The New Nordic Cuisine* (Nordic Council, undated) food movement provides an example of how traditional food values can be revived and cuisine modernised and developed to give a renewed appreciation of the wealth of indigenous and traditional foods of high nutritive and health value.

7.6 Biotechnology

Plant biotechnology is broadly defined as a set of techniques to improve the productivity of plants, animals and micro-organisms, or to make or modify a plant-based product. These techniques 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, and proteomics and transcriptomics); the development of diagnostics; genetic modification; and a newer set of tools collectively referred to as the new plant breeding technologies.

Tissue culture has played an important role in producing disease-free planting material for vegetatively propagated crops such as banana and cassava (Kikulwe *et al.*, 2016) and is an important tool for the conservation, improvement and mass production of African indigenous crops (Opabode, 2017). On the other hand, marker-assisted selection has been used successfully to improve a variety of traits in crops. Examples are the drought tolerance of maize varieties grown in Africa (Beyene *et al.*, 2016), and the resistance to *Striga* of cowpea in Nigeria and sorghum in Sudan (Omoigui *et al.*, 2017; Ali *et al.*, 2016). It has also been applied to developing crop varieties with higher nutritional contents (Andersson *et al.*, 2017).

Fish is an important source of food, which comprises one-third of animal protein intake in Africa. To meet expected demands in fish a threefold increase in production is needed. Aquaculture, an emerging sector in 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 the domestication and of new

species for commercial production and in 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 programmes. Furthermore, in 2010 only 8.2% of the world's total aquaculture production was based on material developed in selective breeding programmes (Teletchea and Fontaine, 2014).

The aquaculture sector is lagging behind plant and farm animal production in applying selective breeding. Nonetheless, this has significant potential. Reported estimates of genetic gain per generation for a key trait such as growth rate average 13%, which means that the potential for growth can be doubled in just six generations of selection. This suggests that the world's aquaculture production could be doubled in just 13 years (Gjedrem and Rye, 2016). Reported gains for resistance to specific diseases are high for both salmonids and shrimp (between 11 and 19%), which is important since diseases often represent the main problem in aquaculture (Teletchea and Fontaine, 2014).

Genetic improvement can also reduce the environmental footprint of aquaculture. For example, a study that investigated the environmental consequences of genetically improving growth rate and feed conversion in an African catfish established that increases in feed conversion reduced the environmental footprint of fish rearing in all the scenarios tested. On the other hand, improving growth rates had a beneficial environmental impact only when rearing density limited farm production. Both improvements raised farm productivity (Besson *et al.*, 2016). These results indicate that determining the genetic basis of feed efficiency in fish with a potential for commercial production in Africa is an important research objective; but they also show that breeding programmes need to be complemented by studies to establish the best management practices to maximise productivity sustainably. At the same time, breeding programmes need to be supported by favourable institutional and policy environments and to be integrated into production systems (Haile *et al.*, 2016). Reported genetic gains for improved disease resistance are also generally very high. Novel tools for phenotyping and genetic and genomic analyses should be used to quantify diversity in wild populations of commercial fish varieties to develop pure stocks and to avoid mating between closely related fish to preserve diversity (Haile *et al.*, 2016).

Molecular markers have successfully been used in modern plant and animal breeding to improve yields and increase crop resilience. Also, several new approaches to plant disease control have been developed, such as enhancing resistance to pathogen-derived resistance from plant genes or antimicrobial proteins that strengthen plant resistance to pathogens. Significant progress has been made over the past few years on some previously unstudied pheromone systems in insects. Some practical applications include mating disruptions that interfere with insects' natural attraction to each other (e.g. sexual confusion creates a cloud that masks natural scent trails) and attract-and-kill target devices coated with insecticide and traps.

Technology innovation can also save time and effort for farmers in Africa. For example, genetically modified crop varieties are labour-saving and reduce the drudgery of agricultural production—especially for women who are often tasked with more labour-intensive tasks such as weeding. A study by Gouse *et al.* (2016) explored the preferences of male and female farmers for an insect resistant (*Bacillus thuringiensis*, also called Bt) and herbicide-tolerant maize produced by smallholder farmers in the KwaZulu-Natal province in South Africa. The study found that women farmers value the labour-saving benefit of herbicide-tolerant maize, which offered insect control was and labour-saving. The researchers found that higher yields were the main reason behind male adoption, while female farmers tended to favour other aspects such as the taste, quality and the ease of farming herbicide-tolerant crops. Women farmers (and children) saved significant time in weeding.

The acceptance of genetically modified technology in African countries has, however, been very mixed, despite the fact that important research activities targeting African-specific problems are taking place on the continent. These include the development of disease-resistant bananas and cassava; vitamin enriched bananas and nitrogen-efficient rice in Uganda (Ainembabazi *et al.*, 2015; Wagaba *et al.*, 2016); insect tolerant cowpea in Nigeria, Niger and Ghana; and drought-tolerant maize in Kenya (Mohammed *et al.*, 2014; Muli *et al.*, 2016). Against this backdrop, NASAC (2015) developed an agricultural biotechnology policymakers' booklet with the aim of presenting African governments and business leaders with a source of scientific evidence to help them in policy- and decision-making processes.

8 Prospects for increasing the efficiency and sustainability of food systems

Food security is only achieved when all the conditions (including optimal nutrition) contained in the FAO (1996) definition of food security are met. A stable year-round supply of nutritious food is essential to achieving food security. For too long, policy and food security monitoring and evaluation at national, regional and global levels have focused on the supply of staple grains only. This focus has to be broadened to include the year-round supply of other foods (animal, fish and plant) that are essential to sound nutrition. This needs to be reflected in the comprehensive policies of countries, supported by appropriate policies, programmes and research investment in sectors that support the production, storage, distribution, trade and marketing of foods. Doing so requires the transformation of agriculture value chains to increase the nutritional value of foods. This change will have multiple benefits for producers and consumers. It will also have a positive influence on the basket of food (such as foods for local consumption rather than for export and foods with a relatively high nutritional value) that households produce or can access economically. The nutrient content and food safety (lack of contamination risk) should all be enhanced. To achieve this, we need national growth and development strategies, and to support research, development and STI strategies and programmes that include a blend of nutrition-specific and nutrition-sensitive approaches. These approaches should seek to increase the overall supply and distribution of healthy, nutrient-dense foods at affordable prices that are delivered through value chains that support sustainable livelihoods for rural households engaged in agricultural value chains (Hendriks and Covic, 2016).

Healthy food environments enable consumers to make nutritious food choices with the potential to improve diets and reduce the burden of malnutrition in all its forms. Food environments refer to the physical, economic, policy and socio-cultural surroundings, opportunities and conditions that influence food choices and nutritional status (Swinburn *et al.*, 2014). They influence the accessibility (physical proximity of food), affordability (food prices) and acceptability of food, and are influenced by consumer food preferences and knowledge (Caspi *et al.*, 2012; Swinburn *et al.*, 2014). Agri-food systems will need to modernise to keep up with global trends and domestic demand while providing livelihoods, employment and entrepreneurship opportunities for a diverse and young population (FAO, 2015a). Modernisation of smallholder agriculture and its integration into the fast-growing agribusiness chains can produce quality products that meet rapidly evolving urban demand, particularly concerning

enhanced food quality, convenience and safety (FAO, 2015a). Meeting this changing consumer demand will require substantial private investment to increase productivity in agri-food value chains, adding value, enhancing labour productivity and creating jobs to produce the food demanded by consumers (FAO, 2015a). This will require the reorientation of agricultural and rural development policies that offer incentives to lower the barriers to the transformation of food and agricultural systems. Similarly, it will require transformation of the research and development sector to provide effective solutions to these critical barriers at all stages of the food system. Particular attention should be given to supporting low-income smallholder farmers in strengthening their capacity to manage risks and adopt effective climate change adaptation strategies (FAO, 2016a).

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, and improved storage and preservation to retain nutritional value; ensure food safety; extend seasonal availability and reduce post-harvest losses (including aflatoxin) and food waste (Hendriks and Covic, 2016). Herein lie unique opportunities for health, nutrition and agriculture professionals to work together in identifying gaps in consumption across the human life cycle that contribute to malnutrition, and to develop crops and food processing techniques to solve these problems in sustainable and culturally acceptable ways.

Issues of food safety are very critical to the advancement of food systems. All countries have regulations and standards that products must meet before reaching the shelf. However, implementation is constrained by a lack of capacity to reach the many small- to medium-scale producers. Testing is often expensive and constrains the approval, distribution and export of foods. Food contamination and waste have to be tackled through STI efforts relevant to Africa.

Food processing has potential to contribute to the reduction of post-harvest losses, enhancement of food safety and quality, creation of diversity, and stabilisation of food supply, reducing the prevalence of seasonal hunger and improving market access. The promotion of food processing can catalyse increases in primary food production. Other benefits of food processing include increased diversity in the food supply, job creation and increased retention of organic waste in farming areas. The growth of the middle class and increased urbanisation are likely to increase demand for processed

foods. National agro-processing strategies and interventions are needed to meet the anticipated rise in demand for these foods. Some possible interventions include the establishment of agro-processing incubators, promotion of local production of food packaging materials, provision of fiscal incentives and promotion of research aimed at developing appropriate processing technologies.

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 can also be used to create products that address specific nutrition needs. Through the blending of starchy staples and foods with complementary nutritional value and application of suitable processing procedures, it is possible to develop nutrient- and energy-enhanced foods to supplement prevailing nutritionally inadequate diets, which are particularly important for infants and young children.

The overuse of agricultural chemicals is often exacerbated by poor post-harvest handling, storage and processing practices, which lead to disease and poor health among workers and consumers. This poses serious risks to humans, animals and the environment. Research and training is urgently needed to address these risks and hazards

Pests and diseases on crops may also lead to the accumulation of mycotoxins, which are secondary metabolites produced by fungi. Since damage to the crop by an insect bite or by disease exposes it to further infections, the contamination of food with mycotoxins can also occur after harvesting, mainly owing to improper or unhygienic practices during storage, processing and transportation (Darwish *et al.*, 2014). Mycotoxins have been reported to be widespread in major African food products, in particular in maize and groundnut products, as well as in spices. Threats to human health are very serious: consumption of large amounts leads to acute toxicity and death, while chronic exposure has several effects. Mycotoxins impair nutrition through their effect on the intestine, leading to reduced nutrient uptake and the development of micronutrient deficiencies. The toxins can cross the placenta and accumulate in breast milk, and therefore unborn and young children are particularly affected, resulting in stunting and underweight. Mycotoxins also lead to hepatic diseases and are strongly associated with the development of cancers (Lombard, 2014). Mycotoxin contamination also affects livestock production in African countries and may result in contaminated milk, eggs or meat products (Shephard and Gelderblom, 2014).

The lack of suitable regulations to prevent food contamination, or their poor enforcement when regulations exist (often regulations are applied for

export goods, but not for the domestic market; Matumba *et al.*, 2017), combined with the low levels of capacity for detection of food toxins, are serious concerns. This is particularly the case in smallholder agricultural settings where farmers produce and store a large proportion of the food they consume and where conventional food surveillance mechanisms are not applied. Poverty exacerbates the problem since it leads to overdependence on one foodstuff and may lead to consumption of contaminated foods because of the lack of alternatives (Shephard and Gelderblom, 2014).

Despite the public health importance of mycotoxins, updated and comprehensive information on the incidence of contamination, prevention and control measures, and health effects on the population are lacking. More epidemiological research is needed to establish patterns of contamination and the health effects of mycotoxins (Darwish *et al.*, 2014). Increased capacity to test and certify products is also required. These include cheaper testing methods and innovative cost-sharing practices required to step up the enforcement of minimum quality standards in food products when the resources for laboratory analysis are available. An example is the recent improvements in fluorescence spectrophotometry for quantifying mycotoxin levels in grains and raw groundnuts (Shephard, 2016). However, the greatest challenge is found in smallholder and subsistence farming systems where resources are very limited and electricity may be absent or unreliable. Rapid and cheap out-of-laboratory analytical techniques designed for field conditions can offer solutions to these problems (Shephard and Gelderblom, 2014). One example is the "Blue Box", a portable testing kit developed by the World Food Programme (2011), which includes a battery-operated reader for use when no electricity is available. These kits have been distributed worldwide to farmers' organisations along with supportive training to enable them to test produce to ensure it does not exceed acceptable levels of toxins, which is also a requirement for accessing private buyers. ICT-based solutions may offer additional tools: for example, the Lab-on-Mobile-Device (LMD) platform can accurately detect mycotoxins using strip tests, which are much cheaper than taking samples to a laboratory. However, farmers must own a smartphone (Dobrovolny, 2013).

Cold chains and refrigeration are largely missing in Africa. Preserving food and reducing food loss is an imperative part of an efficient and sustainable food system. Some of the simpler solutions to improving storage pertain to the development of low-cost, low-tech solutions that can be used in rural areas lacking basic infrastructure (such as paved roads) and services (such as reliable connection to the electricity grid). One example of such technologies is the Purdue Improved Crop Storage (PICS) bag, a triple bagging hermetic sack that was initially designed to prevent the growth of

weevil larvae, a very common storage pest of cowpeas. Between 2007 and 2015 five million bags were sold; the project has now expanded to storage of other crops and provides a good example of the successful licensing of a trademark for the dissemination of technology in developing countries. Purdue Improved Crop Storage also encouraged further private investment in storage solutions for smallholders, a very positive outcome in itself (Lowenberg-DeBoer *et al.*, 2017).

Thermal processing has been widely employed in the food industry for food safety assurance and extending product shelf-life by inhibiting or inactivating microorganisms (Caminiti *et al.*, 2011; Stoica *et al.*, 2013). However, the low rates of electrification in many parts of Africa inhibit the adoption of such technologies. More research and development is needed in modified

atmospheric packaging to extend the shelf life of food, thereby reducing enzymatic activity and the growth of microorganisms, and preventing moisture loss and decay. More investment is also needed in developing and making available solar driers and agro-processing equipment such as shellers and de-pulpers.

There has been little investigation into the application of other technologies that could have significant benefits for food safety in Africa, including non-thermal inactivation technologies such as electromagnetic fields, pulsed electric fields, high-voltage discharge, pulsed light, ionising radiation, microwaves and cold plasma. Hybrid technologies and combinations of these methods have not yet been applied to the indigenous food industry but could hold promise for the transformation of the African food system.

9 Prospects for improving human nutrition, health and productivity

Sound nutrition provides a vital foundation for human development and is central to the realisation of full human potential. When nutrition status improves, it leads to a host of positive outcomes for individuals and families. Improved nutrition in Africa means many more children will live past the age of 5, their growth will be less disrupted, and they will gain in height and weight. Their cognitive abilities will develop more fully, allowing them to learn more both within and outside school. As a result of sufficient nourishment and a positive early environment, children are more likely to get better jobs and fewer illnesses as adults—ageing healthily and living longer to support the African Union Agenda 2063 vision of a prosperous and united Africa.

Most Sub-Saharan African countries have registered moderate reductions in the number of underweight children between 1990 and 2015, except in Southern Africa where the average for the region has not shown significant declines (FAO, 2015a). However, the data from the Global Nutrition Report (International Food Policy Research Institute, 2016) indicate that much more needs to be done to reduce undernutrition and at a far greater pace than current progress. For example, as the Global Nutrition Report 2016 shows, simple extrapolations of the rate of change of anaemia prevalence in women suggest it would take until 2124 to attain a 5% prevalence rate. Malnourished people cannot wait that long for their rights to be respected, protected and promoted.

As indicated earlier, hunger and undernutrition are not the only possible consequences of food insecurity. Since 1995 there has been considerable debate about the link between food insecurity and obesity. Until recently, overweight was inevitably blamed on excessive food intake (Townsend *et al.*, 2001). Frongillo (2013) notes that the belief that food insecurity causes only weight loss and not gain is strongly held and often comes with negative sociological and political overtones about the reasons why people live in poor conditions. However, poverty and food insecurity are both forms of material deprivation that have a range of harmful consequences that could well include excess weight gain (Frongillo, 2013). The paradox (Caballero, 2005) that poverty can make a person obese is being explained, as we reach a better understanding of the mechanisms of food insecurity. We now understand that poverty is a significant predictor of food insecurity, and that food insecurity is a risk factor for poor diets.

Attention should also be given to micronutrient deficiencies and increasing levels of overweight, obesity and non-communicable diseases. This includes more

research to understand consumer behaviour and the responses of food systems to increasing household incomes as well as how to influence demand to increase consumption of nutritious foods. As indicated above, this will require research and technological innovation to find solutions to nutrition problems across the human life cycle, especially at those stages that have a critical impact on the future nutrition, development and potential of future generations. This includes a focus on maternal and child health and nutrition during the first 1,000 days (from conception to 2 years).

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 the nutritional value of foods. Food fortification initiatives such as salt iodisation, 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 programmes for biofortification 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, or decreasing the concentration of anti-nutrient compounds that inhibit the absorption of nutrients (for example phytates and oxalates).

Optimal nutrition should ensure good health and well-being and at the same time reduce the risk of disease (Roberfroid 2000, p. 9). Studies have suggested that the gut microbiome performs numerous important biochemical functions for the host (Kinross *et al.*, 2011). Disorders of the microbiome are associated with many and diverse systemic human diseases, including immune functions (Kinross *et al.*, 2011). 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. 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.

Africa has over 2,000 plant species that include domesticated and semi-domesticated native grains, roots, fruits and vegetables that are considered to be “lost” species for rediscovery and exploitation in modern food systems owing to their innate health and nutritional benefits and a variety of adaptive and resilient properties in the food system (National Research Council, 1996). Many indigenous crops have multiple edible parts such as leaves, fruit, seeds and roots. Optimal utilisation of nutritious indigenous and traditional foods holds potential for diversifying food systems in Africa, especially if more of these can be domesticated and produced in larger quantities. For example, *Amaranthus* is used as a vegetable in many traditional African dishes, but the grain has unique gelatinisation and freeze/thaw characteristics that can be used in foods as stabilisers and thickeners as well as non-food applications such as biodegradable biofilms, paper coatings and laundry starch (Singh and Singh, 2011). Likewise, sorghum, a gluten-free cereal that does not require dehusking, contains various phenolic compounds, plant sterols and policosanols that appear to have health benefits (Taylor and Anyango, 2011). These include antioxidant, anti-inflammatory, cancer-preventing, anti-arrhythmic activities as well as satiety-promoting activities associated with policosanols, which are especially important for diabetic and obese persons (see Taylor and Anyango, 2011).

The sequencing of the human genome and increasing knowledge from genetic profiling of individuals and specific ethnic groups provide opportunities for identifying specific nutrient requirements, metabolism

and response to nutritional and dietary interventions referred to as personalised nutrition. These advances could contribute to public health solutions by reducing the risk and prevalence of nutrition-related diseases. Ferguson *et al.* (2016) explain that personalised nutrition encompasses “omics” technologies (nutrigenomics, transcriptomics, epigenomics, foodomics, metabolomics, metagenomics, etc.) and functional¹⁷ food development.

Health- and consumption-related education programmes are required to promote sound nutrition and curtail possible negative impacts of food system advancement (for example the nutrition transition-related outcomes of overweight, obesity and non-communicable diseases). These principles need to be applied to improve institutional diets (schools and hospitals) and transferred through maternal and child health-care systems to influence the consumption patterns and nutritional outcomes of future generations. Incorporation of nutrition in mainstream education at all levels (from early childhood development programmes) is one powerful way of shaping future consumption patterns. The use of media in this educational endeavour, especially digital learning, ICT applications and national television, is a powerful tool in achieving this objective. But more research is needed to understand consumer behaviour change to design effective programmes in this area. For example, governments can go a step further and ban the advertising of unhealthy foods and eating on national media, but it is not known which media and exposures are the most influential on consumer behaviour in Africa, especially among the millennial population.

¹⁷ Foods developed specifically to promote health or reduce the risk of disease.

10 Increasing the efficiency of STI capacity building and ICT

African academic institutions must work to develop food security and nutrition capacity at all levels of society and across traditional disciplines. Governments need to provide the incentives and funding to initiate this reform, direct it and provide opportunities for closer engagement of researchers and policymakers for mutual learning and benefit. It is important to accelerate efforts to develop the transformational leadership capabilities (including facilitation of dialogue across sectors and levels) needed to manage the dynamics of the change processes required to effectively coordinate and implement nutrition programmes and interventions amidst competing priorities and demands.

To improve on food security and nutrition, African countries need to invest in capacity building, including STI research and development; training and education; communication; monitoring and evaluation; and governance, as well as in building international collaborations. Clear long-term commitment and funding (for both infrastructure and human capacity) are crucial to attaining targets such as improving production and food systems. Research objectives need to be closely aligned with national development priorities and food security and nutrition plans. Also, well-funded national agricultural extension services programmes need to be more closely aligned with these national priorities. Nutrition and health information must be included in extension packages, with a specific focus on the welfare of women and children, and informed by research.

Particular attention should be paid to developing the capacity for analysing “big data”, which is central to the following:

- Monitoring food security and nutrition status of populations and how they change over time and in response to interventions, focusing not only on individual micronutrient status but also on the relationship of combined nutrition deficiencies and health and disease.
- Developing early warning systems.
- Effective use of soil, climate and weather data for improving productivity and resilience and for encouraging more effective use of natural resources.
- Monitoring consumer behaviour, including cultural preferences for determining factors related to consumption.

Investment in qualified staff within government, extension and in supporting research institutes is

crucial, with a particular need for investment in young researchers. Programmes focusing on building entrepreneurship in the food sector will be essential for shaping the future food system, including the capacity to establish and manage research parks and business incubators. These programmes should focus on the youth, capacity building in skills related to food production, reduction of losses, value addition and the development of novel food products. Training and capacity building is required to improve the enforcement of food safety and minimum standards.

Education programmes highlighting the linkages between nutrition and lifestyle and health (obesity and related non-communicable diseases) need to be developed and delivered during formal education and as part of broad national public health campaigns. Exploring traditional and novel communication technologies is important for conveying information across the food system as well as between researchers, policymakers and the public.

In some cases, the capacity of governments for analysis, monitoring and evaluation is weak. To fill this gap, ReSAKSS has been working to support countries to establish country SAKSS platforms that are aimed at improving the quality of policy analysis, review and dialogue, with the ultimate goal of improving the quality of NAFSIP implementation (Bahiigwa *et al.*, 2016). Eleven country SAKSS platforms have been established in the past 4 years and two more SAKSS platforms were expected to have been established before the end of 2016 (Bahiigwa *et al.*, 2016).

Rapid developments in ICT make reaching the most remote village and farmer possible, overcoming many of the former challenges of scientific knowledge transfer and awareness of new technologies and innovations. ICT also provides unique opportunities for three-way communication between scientists, farmers and consumers. Now is the moment for Africa to harness the potential of STI systems to drive agricultural and food system transformation in ways that will meet growing demand for diverse and healthy food and sustainable food systems to support development and growth in Africa.

ICT innovations to better manage animal, fish and plant diseases and post-harvest losses can greatly reduce farmers' exposure to risks and uncertainties alongside improved approaches to control human infectious diseases (FAO, 2015a). ICT innovations also offer multiple opportunities for improving and optimising food systems. The role of ICT in rapid identification of pests and diseases and mapping of their locations and spread are important tools for managing and mitigating

risks due to the spread of pests and diseases, and for increasing the awareness and preparedness of farmers, especially as much of the African food chain is informal. Public awareness of the problems, hazards and solutions is essential.

While fixed-line coverage in Africa is rather low, competition between competitors in this market as well as from cell phone companies is increasing it. Some countries in East Africa have cell phone subscription rates of over 100%. West Africa is less well covered, but catching up (Imbernon, 2016). However, in East Africa, mobile telephony, coupled with innovative pay-as-you-go services, is facilitating trade and enabling access to key services such as electricity, health, education and transport. Mobile phone

companies are partnering with banking services to provide credit, payment and transfers, and can also allow the resource-poor user to build a credit history needed to access more formal financing services such as bank loans and micro-credits (Imbernon, 2016). A recent novel programme in Rwanda will launch an Uber tractor service, demonstrating how innovative applications can revolutionise service delivery and stimulate public-private partnerships in very practical ways. Such innovations could rejuvenate rural economic development. Other applications could include not only access by rural households and farmers to weather, production, price and health information, but also the technologies offer opportunities for two-way communication and submission of geo-referenced crowd-sourced local data.

11 Conclusions

STI offers many promising opportunities for agricultural transformation in Africa. Modern science can unlock the potential and protect the heritage of Africa's nutritious food sources and ensure sustainable and diverse diets. In this report, NASAC tackled the complexity of food and nutrition security and agriculture in Africa, reviewing the key drivers of food insecurity, malnutrition and agricultural growth. The report discussed the strengths and weaknesses of STI capacity in Africa and what is necessary to build a cadre of professionals and researchers with the necessary disciplinary and transdisciplinary skills and knowledge to engage with the growing complexities and pressures from low productivity, population growth and urbanisation, food access and affordability, and stability and resilience.

The discussion was framed within the context of a strong commitment to both agricultural growth as well as ensuring food and nutrition security for all on the continent, as set out in Africa's Agenda 2063, the Malabo Commitments and the CAADP Framework. As recognised by these policies, agricultural growth is a driver of broader development. Agricultural transformation is essential if Africa is to achieve the continental and SDG targets related not only to food security and nutrition but also the SDGs in general. STI offers many promising opportunities for supporting and advancing this transformation. Modern science can unlock the potential and protect the heritage of Africa's nutritious food sources and ensure sustainable and diverse diets. The report outlines the prospects for STI to advance and support this transformation through five strategic areas.

First, the efficiency in government, policies and institutions is required. The intractable and complex nature of food and nutrition security demands transdisciplinary collaboration and inter-sectoral governance. Governments in Africa could benefit from independent knowledge platforms that generate guidance on emerging issues in the global, continental and national food security and nutrition domains. These platforms could support multi-sectoral efforts and multi-institutional platforms for peer review, mutual learning and mutual accountability in line with their Malabo Declaration commitments to policy and programme alignment, harmonisation and coordination. Evidence-based policies and planning require extensive and up-to-date data. Advances in ICT could support the establishment of "big data" systems, analysis and reporting of cross-sectoral data, and monitoring and evaluation of implementation.

Second, the efficiency of the agricultural system needs to be improved, particularly in the face of increasing uncertainties and competition for resources. The sheer number of smallholder farm families in developing

countries justifies a specific focus on the threat posed by climate change to their livelihoods and the urgent need to transform those livelihoods along sustainable pathways. Sustainable agricultural practices can significantly improve food security and improve the resilience of food systems. Competition for land and water comes from many sources, putting stress on existing resources and affecting the food security of nations, communities and households. Modernisation of smallholder agriculture is essential, as well as its integration into the fast-growing agribusiness chains that can produce quality products that meet rapidly evolving urban demand, particularly concerning enhanced food quality, convenience and safety.

It is therefore important to broaden the focus of research to cover crops, livestock and fish as well as feedstock for animals and fish. Appropriate soil improvement practices and informed crop choices are essential to prevent further degradation of Africa's production potential. Many of Africa's food resources are underutilised. Investment in preserving and improving these resources as well as promoting the production and consumption of these foods is important for nutrition as well as long-term resilience amidst climate uncertainty.

Third, there is need to increase the efficiency and stability of food systems. Ensuring a supply of affordable, healthy foods and their year-round availability will require a transformation of the agriculture and food systems in Africa. Raising the productivity of food systems in Africa amidst growing uncertainty and instability to meet future food security is increasingly recognised as a pressing issue. Addressing critical challenges will require an integrated approach that deals with issues pertaining to the sustainable use of natural resources (including water, energy, soils); increasing the productivity of crops and livestock; expanding the number of species used for food production to include neglected indigenous crops; and promoting diversification in livelihood activities.

Fourth, improving human nutrition, health and productivity are necessary to break the cycle of inter-generational poverty and deprivation. Transformation of Africa's food system demands the harnessing of STI to promote product diversification with nutritious foods; processing to extend their shelf life and make healthy foods easier to prepare and improved storage and preservation to retain nutritional value; ensure food safety; extend seasonal availability and reduce post-harvest losses (including aflatoxin) and food waste. Biotechnology holds many possibilities for genetic improvement, increasing the efficiency of production and reducing the environmental footprint of production

systems. While the acceptance of genetically modified organism technology in Africa has been very mixed, biotechnology offers many opportunities to preserve, enhance and improve food production in Africa.

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 the nutritional value of foods. 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. 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.

Finally, the necessary transformation requires significant STI capacity, supported by ICT. Health- and consumption-related education programmes are required to promote sound nutrition and curtail possible negative impacts of food system advancement (for example the nutrition transition-related outcomes of overweight, obesity and non-communicable diseases). Well-funded national agricultural extension services programmes need to be more closely aligned with these national priorities. Nutrition and health information

must be included in extension packages, with a specific focus on the welfare of women and children, and informed by research.

ICT can solve many of the current constraints about access to information, analysis of data, predictions and early warning. Innovations in mobile technology can overcome many trade- and market-related information challenges, link farmers to markets and provide two-way communication between producers, consumers and researchers. They also solve an issue related to the remoteness of rural communities through offering banking, credit and other services.

To improve on food security and nutrition, African countries need to invest in capacity building, including STI research and development; training and education; communication; monitoring and evaluation; and governance, as well as in building international collaborations. Clear long-term commitment and funding (for both infrastructure and human capacity) are crucial to attaining targets such as improving production and food systems. Additional capacity for biotechnology is necessary in Africa, particularly to build a critical mass of expertise that can select, diffuse, adapt and use technologies.

Research objectives need to align with national development priorities as well as food security and nutrition plans. The support, alignment and partnerships between national agricultural research systems, private companies and international research centres are essential.

12 Priority areas for action

The following priorities are highlighted as illustrations of how scientific enquiry can generate information for evidence-based policy, and advance and support transformation of the African agricultural sector and food system to improve food security and reduce malnutrition in Africa:

1 Strong political commitment informed by scientific evidence

- Achieving Africa's ambitious growth and development agenda as set out in Agenda 2063 and the Malabo Declarations will require well-informed policies and action plans, the appropriate institutional arrangements, capacity at all levels and the requisite funding. This will necessitate strong investment from African governments and their funding partners along with the active partnership of the private sector and international research centres.
- Governments should take responsibility for directing this transformation and provide opportunities for the closer engagement of researchers and policymakers for mutual learning and benefit.
- Strategic cooperation in the form of research alliances and partnerships could include the establishment of multi-sectoral and multi-institutional STI platforms as part of national food and nutrition systems for peer review, mutual learning and mutual accountability in line with Malabo Declaration commitments to improve policy and programme alignment, harmonisation and coordination. Multi-sectoral institutional platforms and arrangements can mitigate the challenges of low investment, brain-drain, brain-wastage as well as the fragmented and expensive duplication of efforts.
- Closely monitoring land use change and determining its impacts on food security at different levels – national, community and household – is necessary to protect household food security and ensure that these investments do not degrade the natural environment and that they lead to inclusive economic growth and viable employment opportunities—especially for women and youth.
- Advancing ICT to support multi-sectoral “big data” platforms with the necessary capacity could support ongoing monitoring and evaluation of policies and programmes as well as the efficiency of the agriculture and food systems. This will inform policies and actions, and document the impact of these for mutual learning and refinement of development actions.

2 Agriculture and food system efficiency

- Ensuring quality and sustainable supply of seed and vegetative propagation materials of indigenous and underutilised foods will increase production of these foods, making them more available to consumers. National research systems must support these actions. More investment is necessary to collect and categorise orphan crops and wild populations. Modern molecular breeding technologies offer potential to preserve these resources and increase their availability.
- Improving the efficiency of livestock and aquaculture rearing and feed quality is equally important for food and nutrition security in Africa.
- Advances in appropriate modern technologies, biotechnology and biosciences can provide timely and efficient management of biotic and abiotic factors that limit agricultural productivity and nutrition.
- Applying modern breeding technologies could improve and enhance the diversity and utilisation of indigenous and underutilised foods in Africa.
- Finding solutions that reduce the drudgery in Africa's largely unmechanised farming and food systems can improve equality. This is essential for freeing up women's time in particular.

3 Farming system resilience

- Improving mixed farming systems could improve food productivity amidst greater levels of uncertainty. This could improve prospects for smallholder livelihoods and environmental protection.
- Stakeholders (including farmers) need to work together to improve the resilience of farm systems through climate-smart agriculture approaches. These require supportive public policies and context-appropriate programmes supported by research and development, well-qualified extension staff as well as knowledge and technology transfer on a large scale.
- Monitoring changes in the environment through soil and water mapping can support agricultural production decisions at all levels. Getting this information into the hands of African farmers through ICT applications to support decision making is essential.

4 Food system efficiency, human health and well-being

- STI research can find ways to promote product diversification with nutritious foods; processing to extend shelf life and make healthy foods easier to prepare, and improved storage and preservation to retain nutritional value; ensure food safety; extend seasonal availability and reduce post-harvest losses (including aflatoxin) and food waste. These solutions should consider current changes in demand, predict future demand changes and shape the future of the African food system in ways that will provide nutritious food for all.
- Develop processing and packaging technologies to respond to consumer demands for safe and healthy alternative foods and extend the shelf life of foods. The limitations of water and power supplies need to be considered in developing these technologies.
- Increasing funding for more research into the fortification, biofortification and enrichment of foods can increase the nutritional value of commonly consumed foods, improve the bioavailability of nutrients for absorption and metabolism, or decrease the concentration of anti-nutrient compounds that inhibit the absorption of nutrients (for example phytates and oxalates). A focus on harnessing the inherent properties of indigenous knowledge and foods is needed.

5 Food safety and waste reduction

- Developing technologies to overcome the shortage of cold storage and refrigeration in Africa is necessary, including innovation in processing and packaging to ensure stable, safe foods, particularly in areas where electrification levels are low. The use of solar energy is one possible area to explore.
- Strengthening and enforcing agriculture and food regulations and standards, and building the requisite capacity (human, technological and infrastructure), will ensure food safety and ensure access to export markets.
- Research and training can reduce the risks and hazards associated with the over-use of agricultural chemicals.

- Alternative approaches and techniques can reduce the need for chemicals that are harmful to environment, human health and well-being, yet are affordable and accessible to farm households in Africa
- Empowering farmers to monitor and control the spread of diseases and pests, and enhancing the capacity of farmers with information on digitised soil, weather, cropping and disease information systems to take vital decisions and actions at the farm-level.
- Conducting epidemiological research to establish patterns of contamination and health effects of mycotoxins in Africa can inform better management and containment of these risks. This needs to be complemented with building more capacity to test and certify products, developing innovative and cheaper testing methods (including rapid digital assessments) and stepping up the enforcement of minimum quality standards in food products through innovative cost-sharing practices.

6 Human capacity

- Strengthening the human and infrastructural capacity for agricultural research, innovation and technology will support transformation. African academic institutions must work to develop food security and nutrition capacity at all levels of society and across traditional disciplines. Increased effort is required to ensure a well-trained extension service that is constantly updated.
- Providing support and incentives for stakeholders in the agricultural sector to mentor youth involved in value-addition within the context of economic growth, food security and poverty alleviation will assist in addressing unemployment and bringing young people into the sector. Empowering the youth with appropriate skills and mainstreaming gender considerations in food and nutrition security programmes will take deliberate action on the part of all stakeholders.

Appendix 1 IAP core template for project on food, nutrition and agriculture

The overall goal of the IAP project is to show how science can be engaged to promote and support food and nutrition security. This goal encompasses both (1) the better use of the scientific evidence already available to inform policy options and stimulate innovation, and (2) the identification of knowledge gaps to advise on research priorities to fill those gaps and improve the evidence base for public policy and resource for innovation.

Thus, the criterion for identifying which particular topics to cover is primarily “scientific opportunity” within the context of the IAP project objective to add value to work already done by others.

The initial collective scoping work of the four regional academy networks has been synthesised into the following ten questions and there will be many linkages between these top-level themes.

The ten top-level questions are intended, as the shared starting point, to help inform the framework for each regional academy network Working Group. This does not mean that each regional output needs to conform to a uniform structural format but rather that the issues raised and key messages delivered from all four Working Groups can be subsequently mapped onto the agreed top-level themes, to serve as the resource for the IAP global-level phase.

Individual bullet points listed within each of the ten themes are not intended to be comprehensive or mandatory but illustrative of some specific issues that may be addressed. There will, of course, be others according to the particular evidence reviewed and expertise employed within each region.

1. What are key elements to cover in describing national/regional characteristics for food, nutrition and agriculture?
 - Definitions and conceptual framework for food, nutrition and agriculture including: how measured, links with health, and covering demand-side as well as supply-side issues to assess overall current “fitness for purpose” and clarify boundaries for framing the themes.
 - Including status and standards for population groups (variation within a region, demographic, vulnerable).
 - Covering excess consumption as well as undernutrition.
2. What are major challenges/opportunities for food, nutrition and agriculture and future projections for the region?
 - Climate change (impact of climate change on food, nutrition and agriculture and contribution by agriculture to climate change).
 - Population growth, urbanisation, migration.
 - Supply instabilities and others (e.g. political, economic, financial).
 - Ensuring sustainability (environmental, economic, social), and building resilience to extreme events (e.g. to address increasing systemic risk from interruption of increasingly homogenous food supplies).
 - Agriculture and food in the bio-economy.
 - Scenario building.
3. What are strengths and weaknesses of STI at national/regional level?
 - Relevant cutting-edge capabilities: including social sciences, inter- and transdisciplinary research, modeling.
 - Opportunities and challenges for research systems in the context of tackling major vulnerabilities in food, nutrition and agriculture; relative contributions from public and private sectors.
 - Handling and using “big data” in food and nutrition science/open data opportunities.
 - Issues for mobilising science and deploying outputs from research advances, addressing innovation gaps and ensuring next generation of researchers, farmers, etc.
 - Science-policy interfaces. Sharing science within the region.
 - External (indirect) effects—the impact of research and innovation in the region on outside the region.
4. What are the prospects for innovation to improve agriculture (e.g. next 25 years) - at the farm scale?
 - Issues of societal acceptability.
 - Plants (for example plant breeding, ensuring genetic diversity).
 - Animals (for example the advent of genome editing).
 - Tackling pests and diseases.
 - Food safety issues.
 - Agronomic practices (e.g. precision agriculture).

- Not just terrestrial—also use of aquaculture/ marine resources, developing market potential while avoiding over-exploitation and depletion of genetic diversity.
5. What are the prospects for increasing efficiency of food systems?
 - Understanding the agricultural/food value chain and institutional frameworks to characterise issues for the integrative food system.
 - Issues for food utilisation and minimising waste (including during harvesting, processing, consumption stages).
 - Tackling governance/market/trade issues to ensure affordable food and minimise market instability.
 - Food science issues. Food retail issues.
 6. What are the public health and nutrition issues, particularly with regard to impact of dietary change on food demand and health?
 - Characterising current trends in health-related to issues for FNS.
 - Issues for expected changes in consumption patterns (and implications for food importation); understanding and incentivising behavioural change, emerging personalised nutrition.
 - Innovative foods and new food sources.
 - Food safety issues.
 - Promoting nutrition-sensitive agriculture to provide a healthy and sustainable diet with connected issues for resource use and food prices.
 7. What is the competition for arable land use?
 - Impacts of urbanisation (including issues for agricultural labour force and new opportunities in urban agriculture as well as issues for available arable land).
 - Bioenergy and other bio-economy products.
 - Multifunctional land use - goals for biodiversity and ecosystem services.
 - The potential for expanding arable land availability (for example from marginal land).
 8. What are other major environmental issues associated with food, nutrition and agriculture—at the landscape scale?
 - Implications of forestry trends.
 - Also competition for resources about marine sustainability.
 - The contribution of agriculture to climate change.
 - Intersections with other natural resource inputs (water, energy, soil health) and fertilisers/other chemicals. Irrigation issues in multi-use water systems. Wastewater.
 - Balancing goals for sustainable development and FNS.
 9. What may be the impact of national/regional regulatory frameworks and other sectoral/inter-sectoral public policies on food, nutrition and agriculture?
 - Policies that foster technological innovation.
 - Policies that build human resources (for example education, gender, equity).
 - Policies that redesign whole agricultural ecology (land use, bio-economy, etc.).
 - Policies to promote consumption of healthy food.
 - Issues for policy coherence.
 10. What are some of the implications for inter-regional/global levels?
 - Link with global objectives, for example SDGs and the 2015 United Nations Climate Change Conference (COP21)—issues for their scientific underpinning and resolution of conflicting goals.
 - The wider impact of national/regional policy instruments, for example trade, development policies.
 - International collaboration in food, nutrition and agriculture research and research spillovers.
 - International food, nutrition and agriculture science governance infrastructure and science advisory mechanisms.

Appendix 2 Relevant previous NASAC publications, 2012–2016

The Grand Challenge of Water Security in Africa- Recommendations to Policymakers - published 2014
<http://www.nasaonline.org/attachments/article/193/The%20Grand%20Challenge%20of%20Water%20Security%20in%20Africa-Recommendations%20to%20Policymakers.pdf>

Harnessing Modern Agricultural Biotechnology for Africa's Economic Development - Recommendations to Policymakers - published 2015
<http://www.nasaonline.org/attachments/article/240/Harnessing%20Modern%20Agricultural%20Biotechnology%20for%20Africa's%20Economic%20Development%20-%20Recommendations%20to%20Policymakers.pdf>

Changing Disease Patterns in Africa - Recommendations to Policymakers - published 2015
<http://www.nasaonline.org/attachments/article/241/Changing%20Disease%20Patterns%20in%20Africa%20-%20Recommendations%20to%20Policymakers.pdf>

Climate Change Adaptation and Resilience in Africa - Recommendations to Policymakers - published 2015
<http://www.nasaonline.org/attachments/article/253/Climate%20Change%20Adaptation%20and%20Resilience%20-%20Recommendations%20to%20Policymakers-WEBi.pdf>

Appendix 3 Working Group composition and timetable

This report was prepared by a Working Group of experts acting in an individual capacity and nominated by member academies of NASAC or invited by the Chair of the Steering Committee:

Writing team

Editor: Sheryl Hendriks (South Africa)
Mary Abukutsa-Onyango (Kenya)
Claudia Canales (Norway)
Andrew Kiggundu (Uganda)
Oyebiodun Grace Longe (Nigeria)
John Muyonga (Uganda)
Yogesh Parmessur (Mauritius)

Steering Committee

Mohamed Hassan (Chair, Sudan)
Endeshaw Bekele (Ethiopia)
Douglas Miano (Kenya)
Gassama Yaye Kène (Senegal)
Thameur Chaibi (Tunisia)
Elly Sabiiti (Uganda)

Expert reviewers

Othusitse Madibela (Botswana)
Samuel Kofi Sefa-Dedeh (Ghana)
Paa Kobina Turkson (Ghana)
Dayawatee Goburdhun (Mauritius)
Moroka Makhura (South Africa)
Tsakani Ngomane (South Africa)
Hilda Nyambe (Zambia)
Tobias Takavarasha (Zimbabwe)

NASAC gratefully acknowledges funding for this endeavour from the InterAcademy partnership (IAP) and the German Federal Ministry of Education and Research (BMBF) through the German National Academy of Sciences Leopoldina.

NASAC thanks the Working Group members for their insight, commitment and support, the members of the Steering Committee for their advice and guidance, and the expert reviewers for their valued contribution to improving the earlier versions of this report. The support given by the NASAC secretariat is also highly appreciated.

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The Network of African Science Academies
P. O. Box 201
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Nairobi
Kenya

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ISBN 978-9966-112-00-2



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