INNOVATIONS FOR SUSTAINABLE FOOD SYSTEMS IN AFRICA

Technologies, institutions, partnerships and policies addressed by PARI research 2014-2024

By Heike Baumüller, AO Fatunbi & Joachim von Braun

PARI RESEARCH FINDINGS BY THEMATIC AREA

PARI RESEARCH FINDINGS BY COUNTRY

POLICY IMPLICATIONS

JANUARY 2025

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We thank all our African, Indian, international and German research partners, whose studies are synthesized in this report, for their collaboration, local expertise and commitment. Together, we have been able to conduct research on critical issues for the African continent and India, even under challenging circumstances, while fostering meaningful linkages with local food systems actors.

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PARI RESEARCH PARTNERS 2014-2024

African Economic Research Consortium (AERC)	Kenya (pan-African)
African Growth and Development Policy Modeling Consortium (AGRODEP) facilitated by AKADEMIYA 2063	Rwanda (pan-African)
Agricultural Research Council of Nigeria (ARCN)	Nigeria
AKADEMIYA2063	Rwanda (pan-African)
BioInnovate Africa	Kenya (East African)
Center for Development Research (ZEF), University of Bonn	Germany
Centre de Suivi Ecologique (CSE)	Senegal
CILLS Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (AGRHYMET)	Niger (Sahel region)
CSIR Science and Technology Policy Research Institute (CSIR-STEPRI)	Ghana
Department of Agricultural Research Services of Malawi (DARS)	Malawi
Forum for Agricultural Research in Africa (FARA)	Ghana (pan-African)
Indian Council for Research on International Economic Relations (ICRIER)	India
Initiative Prospective Agricole et Rurale (IPAR)	Senegal
Institut d'Economie Rurale (IER)	Mali
Institut de L'Environment et de Recherches Agricoles (INERA)	Burkina Faso
Institut de Recherche Agricole pour le Development (IRAD)	Cameroon
Institut National de Recherche Agronomique de Tunis (INRAT)	Tunisia
Institut National des Recherches Agricoles du Bénin (INRAB)	Benin
Institut Sénégalais de Recherches Agricoles (ISAR)	Senegal
Institut Togolaise de Recherche Agronomique (ITRA)	Togo
International Food Policy Research Institute	International
International Livestock Research Institute	International
Kenya Agricultural and Livestock Research Organization (KALRO)	Kenya
Lilongwe University of Agriculture & Natural Resources (LUANAR)	Malawi
Makerere University – College of Agricultural & Environmental Sciences	Uganda
National Agricultural Research Organisation (NARO)	Uganda
Policy Studies Institute (PSI)	Ethiopia
Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI)	India
Technical University Munich	Germany
Université Cheikh Anta Diop de Dakar (UCAD)	Senegal
University of Addis Ababa	Ethiopia
University of Ghana – Institute of Statistical, Social and Economic Research	Ghana
University of Hohenheim	Germany
University of Nairobi, School of Computing and Informatics	Kenya
World Aquaculture Society - Africa Chapter	South Africa (pan-African)
Zambia Agriculture Research Institute (ZARI)	Zambia

CONTENTS

SUMMARY

The *Program of Accompanying Research for Agricultural Innovation* (PARI) provides research and independent evidence-based advice to help guide policy and investment decisions to promote agricultural growth, food security, employment generation and food system transformation in Africa and India. The program was launched as part of the 'One World – No Hunger' Initiative (SEWOH) of the German government which sought to promote Sustainable Development Goal (SDG) 2 by improving affordable access to healthy foods. As the accompanying research program to the SEWOH, PARI was tasked with supporting the work of existing African innovation institutions as well as the GIZ-led Green Innovations Centres (GIC) focussed on value chains, set up in the context of the SEWOH to support smallholder farmers in the adoption of innovations that can improve incomes, employment and food supply. In the decade of PARI operation, the conceptual framing of food and agriculture development moved from a value chain to a food systems approach and PARI played a significant role for this transformative change of perspective.

The SEWOH was initiated in response to persistently high rates of food insecurity in Africa and South Asia, the target regions of the initiative. Despite high-level support for the fight against food insecurity, culminating in the launch of the Global Alliance against Hunger and Poverty under the leadership of the Brazilian presidency at the G20 Summit in November 2024, hunger and malnutrition levels remain unacceptably high. Achieving SDG2 by 2030 has become almost unattainable due to insufficient action in the past years and rapidly escalating costs, estimated at additional annual investments of USD 93 billion. To address the scale of the food and hunger crisis in Africa in particular, a longer time horizon than 2030 will be necessary—combining high-impact, urgent short-term measures, such as increased spending on humanitarian assistance and social protection, with long-term investments that take more time to yield results.

This report aims to inform policy and investment decisions to address food insecurity which are urgently needed to achieve significant reductions in hunger (undernourishment) and malnutrition. To this end, it summarizes key findings from 10 years of PARI research and provides roadmaps for policy. Key insights are presented in two ways:

The first section highlights challenges and investment needs in key thematic areas related to different segments of the food value chain as well as cross-cutting issues, such as women and youth engagement, skill development and institutional innovations. The selection of research themes was guided by African policy priorities outlined in continental agreements, the thematic areas addressed by the GICs and the research and policy priorities of PARI partners.

The second section summarizes the results by PARI research countries. The initial selection of countries was based on the focus of the GICs in Africa and India, with additional countries added over time to enable cross-country learning and provide new insights.

The final section of the report offers broader lessons from a decade of PARI research on transforming food systems in Africa to promote affordable and equitable access to healthy foods.

A number of key insights and recommendations emerged from the research:

- **Promote context-specific innovation packages for productivity growth**

Boosting the productivity of African agriculture will require locally adapted innovation packages that combine multiple innovations for maximum impact. There are no silver bullets in food systems and value chains. Key priorities include improving access to high-quality seeds through decentralized seed systems, promoting small-scale irrigation, and enhancing the availability of feed, improved breeds and fingerlings in the livestock and aquaculture sectors. Balancing sustainability trade-offs is crucial to ensure economic, social and environmental goals are achieved.

- **Recognize and scale farmer innovations**

Farmers are a valuable source of scalable and effective innovations. Many independently develop locally adapted solutions address challenges like pest control and livestock health, improving food security, incomes and reducing costs. PARI field research showed that scaling these local innovations needs their recognition and integration into research systems, along with support for documentation, validation and commercialization.

- **Scale locally adapted mechanization and related services**

Mechanization presents significant opportunities to modernize African agricultural production and processing and reducing drudgery of the farm labour force, for women in particular. Expanding their adoption depends on affordable, context-appropriate machinery and related services, support for local machinery manufacturing and investments in financing, skills and infrastructure.

- **Accelerate digitalization in food and agriculture**

Digital technologies could transform African agriculture by boosting productivity and market access. To unlock this potential, efforts should focus on improving digital skills, expanding connectivity, developing integrated digital service platforms and strengthening data protection. Intermediaries play a key role in bridging the "first mile" of the value chain, connecting smallholder farmers to digital services and platforms.

- **Connect producers to markets**

Improving market access for small-scale producers in Africa requires strengthening domestic and intra-African market linkages, investing in infrastructure like cold chains, storage and transport, and fostering farmer associations and public-private partnerships. These measures can improve value chain efficiency, increase competitiveness and incentivise productivity-enhancing investments.

- **Harness the job creation potential of the food sector**

Creating jobs for Africa's youth will be a major challenge in the years ahead. Increasing agricultural productivity and sales can generate income for producers, while the agroprocessing sector offers substantial potential for job creation. To capitalize on these opportunities, it is essential to invest in ongoing workforce development, focusing on building the knowledge and skills needed for modern agriculture and agro-industrial growth.

- **Strengthen the voice and economic empowerment of women**

Women face structural barriers and restrictive social norms that limit their participation in economic activities and decision-making. Their high work time and heavy burdens of both paid and unpaid work negatively impact their well-being and that of their families. Enhancing women's access to land, technologies, education, finance, childcare support and fair wages is essential to enhancing their equality, productivity and income within Africa's food systems.

- **Enhance innovation systems**

Both the development and scaling of innovations will require a stronger innovation ecosystem, with improved access to finance, raw materials, market links and innovation hubs. Related investments and activities need to be designed for the long term because sustainable innovations based on science take time to be impactful. _+Infrastructure gaps remain a major concern. Tailored investment plans that address local conditions and combine infrastructure elements—such as roads, electricity and water—can maximize employment and economic benefits.

- **Encourage India-Africa learning and international cooperation**

Since 2000, Africa and India have experienced significant agricultural growth which has been linked to improved nutrition and health. Despite these advances, India and Africa continue to face high levels of food insecurity. Giving similarities and challenges in agricultural contexts, the regions can learn from each other, for instance on scaling farmer innovations, mechanizing smallholder production systems or commercializing poultry production. Triangular cooperation among Africa, India and Germany in food systems-related research, innovation and capacity strengthening offers opportunities that should be further enhanced by public, civil society and private sector investments and knowledge exchange.

Innovative policy engagement of PARI and its Network

Over the past decade, PARI has made significant contributions to shaping food and agricultural policy through evidence-based recommendations. Initially, PARI – similar to the Green Innovation Centers – focused on *value chains* and their production and markets. Over time, PARI transitioned to a holistic *food systems* approach in German, African and international policy fora and designed PARI research accordingly. PARI has actively engaged in policy processes by publishing nearly 40 policy briefs, organizing around 50 events and disseminating findings through various channels. Key achievements include influencing the strategic direction of SEWOH, contributing to the UN Food Systems Summit by co-facilitating an "African Voice" and feeding insights into its influential Scientific Group, engaging in T20/G20 policy discussions and synthesizing research into a widely circulated book on Africa's food security strategies. PARI has also shared research with the African Union and at the Africa Food Systems Forum, supported the Malabo-Montpellier Forum's policy reports, and fostered collaboration between African and Indian food systems actors through study visits, comparative studies and workshops.

PARI in itself represents an innovative approach to development investments by integrating independent accompanying research into the traditional program cycle, enabling two-way learning, rapid use of emerging insights and reduced overhead costs. However, for this approach to succeed, development management and investment communities must build trust in partnerships and in research. As research capacities in emerging economies continue to grow, partnerships like those fostered by PARI between Germany, Africa and India have significant potential to drive innovation in development cooperation and program management in the future. An external evaluation of PARI further validated its effectiveness, highlighting positive findings and offering strategic recommendations that can guide the design of future PARI-type programs, even beyond the food systems context (Admassie, 2024).

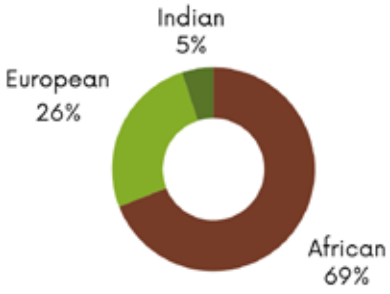
PARI in Numbers

RESEARCHERS

360 authors

87 organisations

26 countries



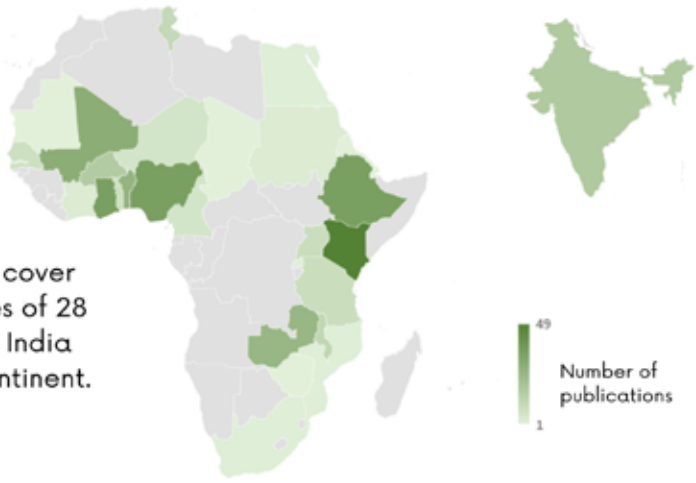
PUBLICATIONS

268 research publications

38 policy briefs

Publications by main research themes:

PARI publications cover key policy priorities of 28 African countries, India and the African continent.



EVENTS

59 research seminars and policy events

in 14 African countries, India, Germany and online

SKILLS

Research grants for

33 Masters students
18 PhD students
from 15 African countries

1 INTRODUCTION

The *Program of Accompanying Research for Agricultural Innovation* (PARI; *Begleitforschung für landwirtschaftliche Innovation)* was launched in 2014 to provide independent evidence-based advice to help guide policy and investment decisions to promote agricultural growth, food security, employment generation and food system transformation in Africa and India (see Box 1). PARI was embedded in the 'One World – No Hunger' Initiative (SEWOH), an ambitious initiative of the German Federal Ministry for Economic Cooperation and Development (BMZ) which sought to promote Sustainable Development Goal (SDG) 2 by improving affordable access to healthy foods. The initiative was launched in response to slowly declining, but nevertheless high rates of food insecurity in the early-2010s, particularly in Africa and South Asia, the target regions of SEWOH. As the accompanying research program to the SEWOH, PARI was tasked with supporting the work of existing African innovation institutions as well as the GIZ-led Green Innovations Centres (GIC)[1] set up in the context of the SEWOH to support smallholder farmers in the adoption of innovations that can improve incomes, employment and food supply.

The topic of food security has risen significantly on the global political agenda since 2014, not least driven by Germany's active efforts to highlight the issue and invest in solutions. A pivotal milestone came in 2015 with the G7 Summit in Elmau, where the G7 countries committed to lifting 500 million people out of hunger and malnutrition by 2030. By 2024, this political momentum had extended to the G20, culminating in the launch of the Global Alliance against Hunger and Poverty under the leadership of the Brazilian presidency at the G20 Summit in November 2024. This alliance aims to mobilize funding and share knowledge to implement public policies and social technologies proven effective in combating global hunger and poverty.

Despite these promising developments, hunger and malnutrition levels remain unacceptably high. The Covid-19 pandemic, global economic decline, conflicts, growing debt burdens and climate change have made the food system more vulnerable (von Braun et al., 2024). Since 2020, the number of food-insecure people has been steadily increasing and by 2023, approximately 730 million people were at risk of hunger and 2.4 billion people faced moderate or severe food insecurity (FAO, 2024a). Progress on key nutrition targets—such as reducing child stunting, child overweight, child wasting and low birthweight—remains insufficient, with these goals unlikely to be achieved by 2030. Certain regions are particularly hard-hit: while global undernourishment has stagnated at around 9% since 2021, Africa has experienced a continuous increase in hunger rates since 2015. By 2023, one in five Africans faced the risk of hunger.

These alarming trends have made achieving Sustainable Development Goal 2 (SDG2) by 2030 increasingly unattainable due to rapidly escalating costs (von Braun et al., 2024). Addressing the needs of 700 million people facing hunger and malnutrition by 2030 would require an estimated USD 93 billion annually (or USD 512 billion between 2025 and 2030) in additional investments for short-term measures. This represents a significant rise compared to the USD 30 billion annual investment required if decisive action had been taken six years earlier. To address the scale of the crisis, a longer time horizon will be necessary—combining high-impact, short-term measures, such as increased spending on humanitarian assistance and social protection, with long-term investments that take more time to yield results.

ABOUT PARI

PARI brings together partners from Africa, India and Germany to conduct research on sustainable agricultural development, food systems transformation and food and nutrition security in Africa and India. To this end, PARI pursues the following interlinked research approaches:

1. Analysis of the **potential and impact of innovations** (which innovations to invest in, where and for whom – considering women, youth, small-scale producers).
2. Identification and assessment of supportive measures to strengthen **framework- and policy conditions for the generation and dissemination of promising innovations** in food systems and rural areas.
3. **Engaging food, nutrition, agriculture and rural areas' science partners and policy makers** to inform reforms and investment decisions that can improve job creation and food and nutrition security.

PARI is led by a consortium of German and African partners, including the Center for Development Research (ZEF) at the University of Bonn, the Forum for Agricultural Research in Africa, the African Growth and Development Policy Modeling Consortium (AGRODEP, initially hosted by the International Food Policy Research Institute and later by AKADEMIYA2063) and the University of Hohenheim. Together, they collaborate with network of around 30 national, regional and international partners based in 15 African countries, Germany and India. (Figure 1; the full list of partners is provided in the Annex and is also available at https://research4agrinnovation.org/partner).

PARI's thematic and geographical focus has evolved over time. A detailed account of this evolution is provided in the External PARI Review 2014-2023 (Admassie, 2024) (Box 1). Further information on the PARI outputs and activities can be found on the PARI Website (Box 2).

ABOUT THE REPORT

This report aims to inform policy and investment decisions to address food insecurity in Africa and India which are urgently needed to achieve significant reductions in hunger and malnutrition. Evidence-based targeting of related interventions will be essential to align with local challenges, priorities and opportunities. To this

1 For further information, see https://www.giz.de/en/worldwide/32209.html. GIC countries include Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Ethiopia, Ghana, India, Kenya, Malawi, Mali, Mozambique, Nigeria, Togo, Tunisia, Viet Nam and Zambia. Some of the GIC projects have been discontinued while the rest is scheduled to wrap up by 2026.

end, the report summarizes key findings from ten years of PARI research and provides a roadmap for actionable insights. The report draws on over 300 studies which have been prepared by the PARI research network. The report is structured as follows:

Section 2 presents key insights on selected thematic areas covered in PARI research. Over the project period, research themes were guided by African policy priorities outlined in continental agreements, the thematic areas addressed by the GICs and the research and policy priorities of PARI partners. This section explores various aspects of the food value chain, including agricultural production, value addition and marketing, as well as cross-cutting food systems issues such as women and youth engagement, skill development, infrastructure, sustainability and supportive institutions. Additionally, it captures learnings from the impact of the COVID-19 pandemic on the food and agriculture sectors in Africa and India. Each sub-section concludes with a list of selected publications for further reading.

Section 3 summarizes key findings for each PARI research country. The initial selection of countries was based on the focus of the GICs in Africa and India, with additional countries added over time to enable cross-country learning and provide new insights.

Section 4 offers broader lessons from a decade of PARI research on transforming food systems in Africa to promote affordable and equitable access to healthy foods.

Figure 1: *Core PARI partners 2014-2024*

PARI Research and Partnership meeting 2024, Ghana

BOX 1: MAIN CONCLUSIONS OF THE EXTERNAL REVIEW OF PARI 2014-2023

While PARI's overarching goal was maintained throughout the project period, some refocusing of the specific thematic areas was necessary to accommodate new challenges and expectations. Accordingly, several new strategic focus areas have been identified and implemented based on changes in local and international circumstances. Rather than focusing only on one location or value chain, there has been a shift towards a scaling up of innovations that are of relevance across a number of countries or sub-regions. Some emerging issues through various phases of the project include promoting rural development and rural-urban linkages, with a particular focus on youth employment and skills development, creating decent jobs and supporting sustainable and fair food systems through digital opportunities.

PARI is well aligned with African priorities on food and agriculture and the German government's overall strategy for Africa and its agriculture sector in particular. The project's complementarity to these strategies and ambitions is demonstrated through a review of the various African policy documents that seek to advance the food and agriculture sector on the continent (including Agenda 2063; the Comprehensive African Agricultural Development Programme; the Science Agenda for Agriculture in Africa; the Science, Technology and Innovation Strategy for Africa 2024; and the Feed Africa strategy of the African Development Bank), the German government's strategy on Africa and PARI interventions.

PARI has produced commendable results in terms of scientific outputs, capacity-building interventions, networking and policy engagement. This is exemplified by the number of publications it had produced by the end of 2023 (278) and the number of experts it has engaged (>300 from around 75 organisations in 25 countries). Particularly noteworthy is the extensive engagement of African researchers which constitute more than 70 percent of the authors of PARI publications and the strong Africa-India exchange. The network of African, Indian and German researchers created over the years is one of the outstanding features of PARI which will persist even beyond the duration of the project. In addition, PARI's long-term impact will be supported through its capacity-building efforts, provided both directly through financial support to 52 Masters and PhD students and indirectly through close and long-standing collaborations between the PARI research partners.

Research dissemination and policy engagement have been central elements of PARI throughout the project period. They were achieved through the organisation of 44 PARI events, participation in external events, the PARI website as well as social and traditional media outreach activities. Notably, PARI regularly hosted events and participated in sessions at the annual African Green Revolution Forum (now Africa Food System Forum) which brings together the leading policy actors engaged in African food and agriculture. PARI also played an important role in mobilizing African contributions to the UNFSS, through FARA and other African partners.

While PARI has made notable contributions during the last ten years, there are some areas that will require further attention, consideration and improvement in the next phase of the project. **To address the challenges faced by PARI during the implementation of project activities, additional efforts should focus on**

- further strengthening the capacities of the African partner institutions and researchers,
- broadening the focus on research partners from Africa's national agricultural research systems to include regional research organisations and universities and
- expanding outreach to and engagement with policy makers on both the African and the German side.

Based on the African continental development strategies, the German Africa strategy and feedback from PARI partners and network groups, the next phase of the project may require a focus on both existing thematic areas and new ones:

- Major areas suggested to be continued from the previous phase include mechanization, digitalization, employment generation, engagement of youth and women, market access, input delivery and Africa-India exchange.
- Examples of possible topics for more in-depth analysis include policy reform, climate change and adaptation, green energy, nutrition security, conflict, governance and rural infrastructure.
- While the challenges facing the African agriculture and food system are many and diverse, PARI 2.0 could contribute significantly if it focuses in particular on agricultural production for food and nutrition security, climate change and adaptation issues, natural resource management, green rural energy production and digitalization for agricultural development.

The review was conducted by Prof. Assefa Admassie, University of Addis Ababa. The purpose was to assess whether PARI is aligned with African and German policy priorities, evaluate the outcomes of the project and their relevance and likely sustainability and identify thematic areas for the next phase of the project. The exercise also offers thoughts on assessment and evaluation approaches to other accompanying research activities. The insights are based on reviewing publications and conducting Key Informant Interviews.

Source: Admassie (2024)

BOX 2: A DIGITAL GUIDE TO PARI

The PARI website provides a user-friendly platform to access PARI research outputs as well as information about PARI news, events and partners. All publications produced by the PARI team are accessible via the respective country pages or a search tool that allows for free word searches and filtering publications by research country, theme and publication year:

research4agrinnovation.org

2 PARI RESEARCH FINDINGS BY THEMATIC AREA

2.1 CROP PRODUCTION

KEY TAKEAWAYS

Reducing yield gaps: Africa's cereal yields lag behind global averages, but locally tailored innovation packages combining for instance optimized fertilizer use, high-yield cultivars and better farming practices can significantly boost productivity.

Fertilizer challenges: Low fertilizer use in Africa contributes to declining yields. Addressing high costs, supply chain issues and low-quality or fraudulent products requires coordinated policies and private-sector engagement.

Organic fertilizer potential: Organic fertilizer, especially when combined with mineral fertilizer, can boost productivity, but the high levels required could pose labour and transport challenges.

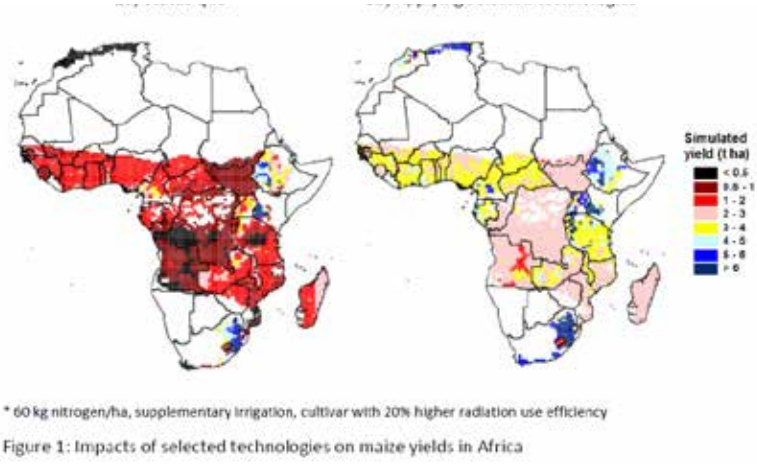
Improving seed systems: Adoption of improved seeds is low, with most seeds being farm-saved. Decentralized seed systems, long-term funding and better dissemination of information can enhance seed availability and use.

Herbicide trade-offs: Herbicides improve yields but reduce edible "weeds" that are critical for nutrition during lean seasons. Policies must balance productivity gains with nutrition security.

Locally tailored innovation packages—such as optimal fertilizer application, high-yield cultivars and improved farming practices—can significantly enhance agricultural yields in Africa (Rezaei and Gaiser, 2018). While agriculture remains a cornerstone of African economies, employing the majority of the population and supporting over 60% of rural livelihoods, productivity lags far behind global standards. For instance, yields of six major cereals (maize, wheat, millet, sorghum, rice and barley) consistently fall below 50% of the global average. Maize and wheat yields, in particular, achieve just 20% of their potential, underscoring that yield gaps are driven more by poor crop management than by climatic or soil limitations. Advancing soil, water and cultivar management practices could significantly boost land productivity (Figure 2).

The following section summarizes PARI findings related to fertilizer, seeds and herbicides. Research findings related to irrigation and energy are presented in section 2.9 (infrastructure) while section 2.10 addresses issues related to sustainable production methods.

Figure 2: *Impacts of selected technologies on maize yields in Africa*



Source: Rezaei and Gaiser (2017)

Fertilizer

Sustainably increasing fertilizer use in Africa requires strengthening the supply chain, implementing supportive taxation and subsidy policies and improving access to information on fertilizer availability, usage and safety (Olaleye and Edje, 2020; Rezaei and Gaiser, 2018). Africa, soil nutrient depletion—aggravated by insufficient use of external inputs like inorganic fertilizers—has led to widespread soil degradation and declining crop yields. African farmers apply an average of just 22 kg/ha (in 2022), far below the global average of 113 kg/ha (FAO, 2024b). Addressing this gap demands comprehensive reforms. Challenges include unfavorable policies, such as high costs from subsidies (e.g. Nigeria), supply chain bottlenecks (e.g. Uganda) and additional tax burdens like the 18% VAT that inflates prices. Issues such as mislabeled or adulterated fertilizers further harm soil health and pose risks to human health when misused. Weak information dissemination and poor coordination among intermediaries exacerbate these problems. Given nitrogen's critical role in plant growth, coordinated policy reforms and private-sector engagement are essential to ensure efficient fertilizer use. Strategic interventions should address affordability, availability and proper usage to promote adequate, sustainable and efficient use of fertilizers.

Yield gaps in Africa could be reduced through the application of organic fertilizer, with even greater impacts when combined with mineral fertilizer. A meta-analysis of 39 studies that investigated the effect of different agroecological practices on land and labour productivity in Africa (e.g. organic fertilizer, crop rotation, intercropping etc.) shows that these practices are associated with a positive and significant difference in land productivity compared to monocrop systems, particularly when monocrops are grown without inputs (Romero Antonio et al., 2024). Among these practices, organic fertilizer most consistently demonstrated yield gains, especially when paired with even small amounts of mineral fertilizer. However, achieving these results would require a significant increase in the amount of organic fertilizer applied which was much higher in the experiments than what is currently feasible in Africa. Such increases would have serious implications for labour and transport demands.

Seeds

The adoption of improved seeds among smallholder farmers in Africa remains low for most crops, underscoring the need for policies and investments to enhance seed systems (Christinck et al., 2018). Despite international initiatives, 70–80% of seeds used in Africa are farm-saved, with maize being a notable exception, showing certified seed adoption rates of about 25% in Southern and Eastern Africa. Seed systems across the continent differ in structure, organization and reach, as illustrated by a comparative study in Kenya and Mali. However, shared challenges persist. The availability of new varieties is limited, particularly in areas affected by climate variability and poor soil fertility. Breeding programs often fail to systematically incorporate important quality and use-related traits. Additionally, slow and costly variety release processes, insufficient information dissemination about new seeds and cash-flow constraints across various stages of the seed system hinder progress. Addressing these barriers through targeted investments, streamlined regulatory procedures and improved dissemination of seed-related information is essential to foster the adoption of high-quality seeds.

Strengthening seed systems requires a comprehensive and integrated approach to improve seed quality, availability and accessibility (Christinck et al., 2018; PARI, 2019a). Farmers' demands for specific varietal and quality improvements must be central to seed system development. Long-term funding is essential to sustain the continuous development of new varieties, ensuring the durability of seed system initiatives. Innovative institutional arrangements should be pursued to enhance access to improved seeds. These include decentralized certification processes, closer involvement of farmer cooperatives and their networks and stronger collaboration among seed system stakeholders. Improved sharing of varietal information, thorough cost-benefit assessments and greater engagement of rural actors in the seed trade can further support accessibility and adoption.

Decentralized seed services offer a promising strategy to enhance the availability and accessibility of quality seeds for smallholder farmers in Africa (Waithaka et al., 2021). An evaluation of decentralization efforts in Uganda and Tanzania highlights a growing number of stakeholders in the seed sector, including an increase in community seed banks and stronger interactions among them. The production of Quality Declared Seed (QDS) has also expanded, supported by new regulations that address previously unclear areas and introduce fees for inspections, germination and moisture testing, among other processes. Despite these advancements, several challenges persist. In Tanzania, for instance, the management of plant genetic resources remains only partially decentralized and seed testing in both countries still requires further decentralization. Additionally, many community seed banks and QDS farmers struggle with financial sustainability, limiting the full potential of decentralized seed systems.

Herbicides

Policies and investments to promote herbicide use need to consider potentially negative impacts on the availability of edible "weeds" which are still widely consumed in Africa. Herbicide use has been associated largely with increasing land productivity and environmental degradation, but not with smallholder farmers' nutrition (Daum et al., 2021b). Herbicides are chemicals designed to control or eliminate weeds and promote the growth of crops. However, in cultivating crops there are also edible "weeds", which are a crucial element from the rural food baskets. During the lean season, edible "weeds" contribute to food and nutrition security among households in Zambia. Yet, the increasing use of herbicide is compromising the availability of edible weeds. The decrease of consumption of edible weeds is more evident among those households that have used herbicides for long periods of time. In promoting the use of herbicide, there must be a close monitoring of the trade-offs with food and nutrition security.

Policies and investments aimed at promoting herbicide use must carefully consider the potential negative impacts on the availability of edible "weeds," which remain a vital part of rural diets in Africa (Daum et al., 2021b). Herbicides are chemical agents designed to control or eliminate weeds to boost crop yields. However, their effects on smallholder farmers' nutrition are often overlooked. Many "weeds" are edible and play a crucial role in rural food baskets, particularly during the lean season. In Zambia, for instance, these edible plants significantly contribute to household food and nutrition security. The growing reliance on herbicides has been linked to a decline in the availability and consumption of these plants, especially among households with prolonged herbicide use. To balance the benefits of herbicide use with potential nutritional trade-offs, it is essential to monitor and address the implications for food and nutrition security in smallholder communities.

Selected publications

Christinck, A., Rattunde, F., Kergna, A.O., Mulinge, W., Weltzien, E., 2018. Identifying Options for the Development of Sustainable Seed Systems – Insights from Kenya and Mali (ZEF Working Paper No. 165). Center for Development Research, University of Bonn, Bonn.

Daum, T., Vehre, A., Schweizerhof, C., Schunko, C., 2021. Edible weeds and food and nutrition security in the face of the herbicide revolution. A case study from Zambia. Int. J. Agric. Sustain. 20, 1166–1180. https://doi.org/10.1080/14735903.2022.2065949

Rezaei, E.E., Gaiser, T., 2018. Yield effects of selected agronomic innovation packages in maize cropping systems of six countries in SubSaharan Africa (ZEF-Discussion Papers on Development Policy No. 257). Center for Development Research, University of Bonn, Bonn.

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2.2 ANIMAL HUSBANDRY

KEY TAKEAWAYS

Growing demand for animal-based products: Population and GDP growth in Africa are driving higher demand for animal-sourced foods, creating opportunities for private-sector investments and innovative solutions to boost livestock productivity and sustainability.

Tailored policies needed: Africa's diverse livestock systems require adaptable policies to address socio-economic and environmental challenges effectively.

Opportunities in the dairy sector: Rising milk demand offers potential for small-scale producers, but investments in affordable feed, improved forages and research-driven solutions are essential to enhance productivity and reduce costs.

Neglected livestock species: Smaller species like grasscutters and guinea fowl offer sustainability and nutrition benefits but face challenges such as disease, limited research and poor market infrastructure.

Uneven aquaculture growth: Aquaculture growth in Africa is slow and uneven, with Egypt leading in production and countries like Lesotho excelling in high-value exports.

Scaling aquaculture: Policies must address market linkages, infrastructure and research, with key actions including decentralizing seed and feed production, promoting sustainable fish farming and integrating producers into value chains.

Livestock

Population and GDP growth will drive rising demand for animal-sourced foods in Africa, but the region will likely remain a net importer. Boosting productivity, sustainability, and resilience in the livestock sector will require innovative solutions (Seré, 2020). As trade in animal-sourced foods becomes more formalized and urban consumers increasingly demand higher food safety and quality standards, these trends will create opportunities for private-sector investments across diverse value chains. To meet these growing demands, institutional and technical innovations are essential to address the challenges of intensifying livestock production. Key innovations include improved forages, better fodder conservation techniques, artificial insemination combined with estrus synchronization, intensive beekeeping practices, livestock master plans, livestock asset transfer programs, index-based livestock insurance and enhanced livestock market information systems.

Africa's rapidly growing livestock sectors are highly diverse, necessitating well-targeted policies and innovations to support sustainable development. Production systems range from extensive pastoralist systems in drylands to smallholder mixed crop-livestock-tree systems in humid and sub-humid zones, smallholder dairy systems in the East African highlands, backyard poultry systems and large-scale commercial poultry operations in coastal and metropolitan areas (Seré, 2020). Livestock keepers respond differently to environmental and socio-economic pressures and opportunities. For example, a study conducted in Burkina Faso, Kenya and Zambia identified two key trends: transitioning farmers adjusted their herd composition while maintaining their existing livestock management systems, whereas transformative farmers completely shifted their herding practices to adopt entirely new systems (Kariuki et al., 2024). To remain effective, livestock policies and governance structures must adapt to the dynamic and context-specific nature of these systems, as well as their broader socio-economic and environmental conditions.

The dairy sector offers opportunities for small-scale producers due to rising demand for milk. Achieving these opportunities requires investments in affordable, high-quality feed to reduce costs, boost productivity and improve animal health (Dickhoefer et al., 2018). In East Africa, dairy cattle feeding primarily depends on grazing native pastures, supplemented by limited cultivated forages, crop residues and agro-industrial by-products. Increasing the efficiency of protein intake through concentrate mixtures could reduce nitrogen losses and enhance feed protein utilization for milk production. Additionally, incorporating forage legumes such as silverleaf desmodium and velvet beans into feeding systems could replace up to 50% of protein concentrates, cutting daily feeding costs by as much as 14% without compromising milk yield. To address seasonal fluctuations in forage availability and nutritional quality, research should prioritize improving local forage options. Small- and medium-scale tropical dairy farmers would benefit from access to context-specific, research-driven knowledge and practical solutions tailored to their needs (PARI, 2019b).

Greater emphasis should be placed on supporting the use of neglected livestock species, which hold significant potential to enhance sustainability while improving nutrition, boosting incomes and empowering women (Oguche, Kariuki, and Birner, 2021). These species can offer high-quality protein, low fat content and a high dressing percentage, making them valuable for both health and economic benefits. Similarly, smaller livestock like grasscutters, guinea pigs, guinea fowl and rabbits have less environmental impacts, such as reduced soil compaction and require less land for production. Despite these advantages, widespread adoption of these species is hindered by several challenges. These include issues related to feed and nutrition, susceptibility to diseases and pests, the absence of supportive policies and strategies, limited research and inadequate extension services. Additionally, infrastructural gaps, such as poorly developed markets, further restrict the potential of these livestock species.

The rapid growth of India's poultry and dairy sectors underscores the importance of combining a supportive policy environment with an active private sector to drive livestock production expansion (Gulati and Juneja, 2023a, 2023b; PARI, 2024a). The foundation for the "White Revolution" was laid during Operation Flood in the 1970s, which established a "National Milk Grid" to connect surplus milk-producing states with milk-deficit regions. The private sector has played a pivotal role in adopting new technologies to improve dairy herd productivity and enhance milk quality. Today, milk is India's largest agricultural commodity, providing livelihoods to millions of rural households. Meanwhile, the poultry sector has emerged as the fastest-growing agricultural sector in India over the past two decades. This growth has been driven primarily by the liberalization of imports of grandparent poultry stock and the adoption of a vertical integration model, which links large integrators with small farmers through contract farming. Despite these successes, challenges persist. In the dairy sector, smallholders face issues such as limited access to finance, low milk yields and an unorganized raw milk procurement system. Similarly, poultry businesses are constrained by limited capital for scaling production and processing, inadequate feed supplies and difficulties in meeting export market standards.

Aquaculture

The growth of aquaculture production in Africa remains slow overall, though there are notable exceptions that offer valuable lessons for other countries (Hinrichsen et al., 2022). While aquaculture production has gradually increased across the continent, progress has been uneven, despite the apparent abundance of natural resources and rising demand for blue foods. Development in the sector varies widely between countries and depends on factors such as water availability, macroeconomic conditions, access to capture fisheries resources and other influencing elements. Egypt leads African aquaculture in terms of absolute production volume and value, followed by Nigeria. In 2022, Egypt's aquaculture output exceeded that of all other African countries combined (Figure 3). Meanwhile, countries like Rwanda, Burundi, Lesotho and Benin have achieved substantial growth rates over the past decade, albeit starting from lower baseline levels. Additionally, Lesotho, South Africa and Mauritius stand out for their high production value per ton, primarily due to the cultivation of high-value species for export (Figure 4).

Figure 3: *Aquaculture production volume (2018)*

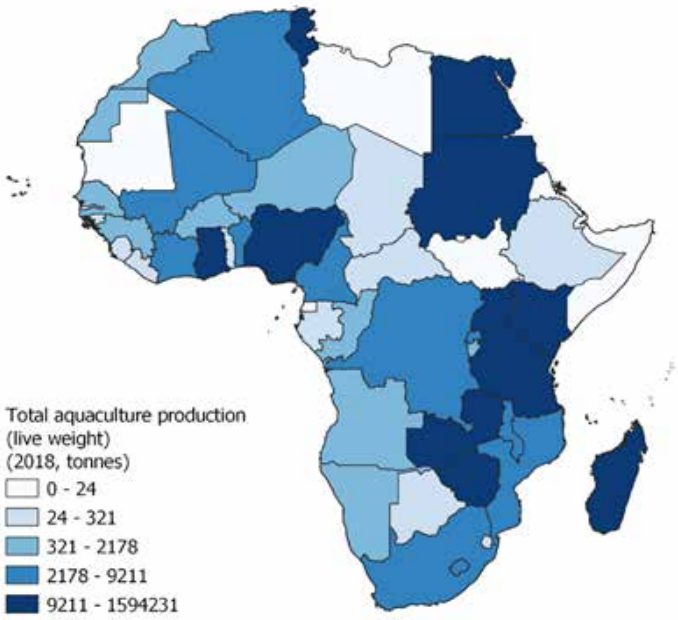
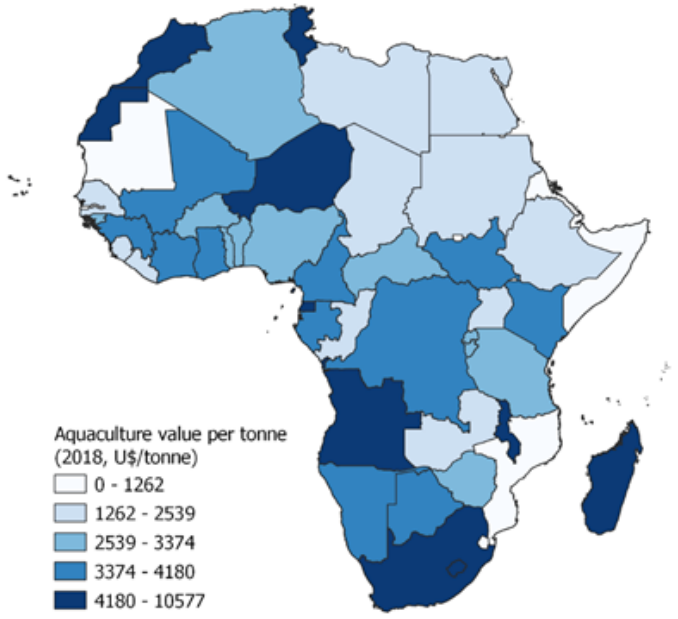


Figure 4: *Aquaculture value per tonne (2018)*



Source: Hinrichsen et al., 2022

To scale aquaculture sectors in Africa, a comprehensive set of policy measures is needed that extends beyond simply increasing productivity to also focus on connecting producers with markets (PARI, 2023a; Walakira et al., 2023). A study examining lessons from Egypt, Kenya and Nigeria highlights several barriers to growth in the sector, including inadequate infrastructure, limited development capital, information gaps, insufficient technological expertise and poor governance, among other challenges National policies must aim to enhance productive capacity while also addressing market linkages, supporting high-potential regions, increasing local research capacity and effectively scaling research outcomes. Key interventions should include decentralizing seed and feed production to improve access, promoting sustainably farmed fish as a valuable source of animal protein and ensuring that producers are better integrated into value chains. By addressing these structural issues, African aquaculture could achieve more inclusive and sustainable growth.

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2.3 FARMER INNOVATIONS

KEY TAKEAWAYS

Farmer innovations: Farmers independently create locally adapted innovations, addressing challenges like pest control and livestock health, improving food security and incomes while reducing costs.

Innovation contests: Contests in several African countries reward farmer ingenuity, spotlighting solutions like plant-based biopesticides and raising awareness of farmers' contributions.

Scaling support: Farmer innovations need recognition and integration into research systems, with support for documentation, validation, agribusiness links and commercialization to boost adoption.

Grassroots models: India's Honey Bee Network shows the value of decentralized grassroots innovation, with Kenya emerging as a potential hub for adapting and scaling such solutions in Africa.

Traditionally, agricultural innovations have been attributed to research organizations. However, farmers themselves also develop locally adapted innovations that can be rapidly and cost-effectively disseminated (Tambo, 2018; Tambo and Wünscher, 2016). These farmer-driven innovations include technologies and practices applicable across the value chain. They differ from traditional or common methods and are created independently by individual farmers or groups without external assistance. Such innovations arise from modifying existing technologies, inventing new practices, or experimenting with novel ideas. They address agricultural challenges by generating site-appropriate solutions. Importantly, enhancing farmers' innovation capacity could empower them to autonomously adapt to changing conditions.

Initially conceived and piloted by ZEF in Ghana, the Farmer Innovation Contests were later scaled to Kenya, Malawi, Zambia, Mali and Cameroon. These contests aim to identify and stimulate high-potential innovations that are easy to adapt and disseminate. By centering farmers in the process and rewarding innovations created "by farmers, for farmers," the contests recognize and amplify the role of local ingenuity. Experiences in Ghana reveal that farmer innovations significantly increase household income and consumption. They also improve food security by boosting household food consumption expenditure, shortening periods of food shortages and reducing hunger severity (Tambo and Wünscher, 2016).

Insights from four PARI-led innovation contests underscore the significant innovative potential of farmers, particularly in pest control and livestock health (Tambo, 2018). In Ethiopia, Kenya, Malawi and Zambia, the contests identified primarily technical innovations, with relatively few institutional innovations. The most common areas of innovation were livestock, crop management and soil and water management. Many farmers utilized local resources to develop plant-based biopesticides and ethnoveterinary medicines, reducing production costs and enhancing food production. This highlights the rich ethnobotanical knowledge and innovation potential among farmers, which should be harnessed and supported. These experiences show that contests offer an effective platform for identifying and rewarding farmer innovators while also raising awareness of their contributions among stakeholders.

Kodaclom Brooder
Cornelius Otieno Obonyo, Kenya

Nyachirambo livestock booster
Jane Chirambo, Malawi

Nthupa pig shampoo
Lisbon Mbale (21), Malawi

Eight-row planter of seed and fertilizer
Adane Alemu Timkete (27), Ethiopia

Stimulating the development and adoption of farmer innovations requires greater recognition of their value within formal research systems. Support measures must also be directed toward innovators (PARI, 2016). Farmer-driven innovations should be acknowledged as critical contributions to agricultural development, with incentives provided to encourage their creation and integration into formal research activities and extension services. Detailed documentation of successful innovations and their dissemination through local extension systems could further facilitate adoption. Follow-up actions, such as scientific validation, value addition, linking farmers with small- and medium-sized agribusinesses and commercializing promising products, will also be essential for scaling these innovations.

An important issue in the context of farmer innovation is the lack of awareness and understanding of intellectual property rights (IPRs) among many innovators (Tambo et al., 2020) they are also an important source of agricultural innovations. They invent farm tools and equipment, develop new crop varieties, and add value to externally promoted technologies. When scouting, documenting and promoting such farmergenerated innovations, the thorny issue of intellectual property rights (IPRs. Concerns have been raised that IPR-driven systems often fail to benefit smallholder farmers and may even have negative consequences, such as contributing to agrobiodiversity loss, increasing the costs of building on earlier innovations and enabling the piracy of farmer-generated innovations. This can overlook farmers' vital contributions to plant genetic resource conservation. A study conducted in Kenya, Malawi and Zambia revealed that most small-scale farmer-innovators (79%) prefer open access to their innovations, largely motivated by altruism. Those who favour IPR protection are motivated by potential financial benefits or wish to prevent poor-quality imitations of their innovations.

Valuable lessons for African farmer innovators can be drawn from the Indian Honey Bee Network's decentralized model for collecting, verifying and disseminating grassroots innovations (Gupta et al., 2019). The Honey Bee Network brings together governmental and non-governmental institutions, academics, scholars and a large network of volunteers to scout, refine and scale up locally designed solutions and traditional knowledge. The Network collaborates directly with innovators to help their ideas reach their full commercial or non-commercial potential. Notably, it has also facilitated the transfer of grassroots technologies from India to Kenya, including a food processing machine, a seed-sowing device and a small tractor. These pilot programs allowed grassroots actors in Kenya to co-design and adapt solutions to fit the local context. The experience highlighted Kenya's potential as a hub for an African grassroots innovation network, given its rich traditional knowledge systems, institutional willingness and recognition of the informal sector's dynamism. Furthermore, the Kenyan experience demonstrated the value of grassroots innovation in addressing local challenges and revealed a strong interest in further investment in similar initiatives.

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PARI reseachers visiting the Honey Bee Network in India

2.4 MECHANIZATION

KEY TAKEAWAYS

Low mechanization hampers productivity: Africa's agriculture relies on basic tools, limiting productivity and causing post-harvest losses. Barriers include small farm sizes, weak financing, and inadequate extension services.

Mechanization tailored to local needs: Solutions must fit regional conditions, such as animal traction or small-scale tractors, with policymakers enabling affordable access through partnerships and strategies.

Mechanization's transformative potential: Increased mechanization can enhance productivity, reduce poverty, and improve food security, but efforts must address sustainability and social risks like deforestation and inequality.

Local manufacturing and investment: Developing African-made machinery requires investments in financing, skills training, infrastructure, and supportive regulations.

Lessons from India: Models like Custom Hiring Centres (CHCs) and private sector investment have successfully scaled affordable mechanization, offering replicable strategies for Africa.

This section focuses on mechanization at the production level. Insights on mechanization and automation in agroprocessing are summarized in section 2.5.

Trends and drivers

The African food and agriculture sectors are characThe African food and agriculture sectors are characterized by low levels of power-driven mechanization, although variations exist between countries. This low mechanization is largely attributed to institutional factors often overlooked by policy systems. Light hand-held and animal-powered tools remain the dominant types of machinery in use (Kirui, 2019; PARI, 2019c). The limited adoption of machinery also exposes farmers to significant post-harvest losses, such as grain shattering, spillage during transport and biodeterioration at various stages, including storage. For example, in the East and Southern Africa region, annual cereal losses ranged between 14% and 17% from 2003 to 2009 (Fatunbi and Odogola, 2018). Several factors influence the adoption of mechanization technologies. Farmers are more likely to adopt tractor-powered mechanization if they cultivate larger land areas, have higher levels of education and have access to finance and extension services (Kirui, 2019).

The diverse mechanization landscape across African countries presents opportunities for cross-country learning (Kirui and von Braun, 2018). Some nations, including Angola, Botswana, Ethiopia, Malawi, Mali, Morocco, Niger, Rwanda, Tanzania, Togo and Zambia, have achieved simultaneous growth in both agricultural machinery use and agricultural output. Conversely, countries like Côte d'Ivoire, DRC, Kenya, Madagascar, Nigeria, Tunisia, Uganda and Zimbabwe have experienced low growth in both areas. Policymakers can draw valuable lessons from both high-growth cases and countries with moderate machinery expansion. While the correlation between agricultural machinery growth and output growth suggests interdependence, it does not imply causality. Advancing mechanization efforts requires detailed, country-specific analyses of the determinants, costs, benefits and institutional frameworks. Strategic policymaking should address both local and national levels, prioritizing initiatives such as machinery imports, service contracts and the development of domestic agricultural machinery industries.

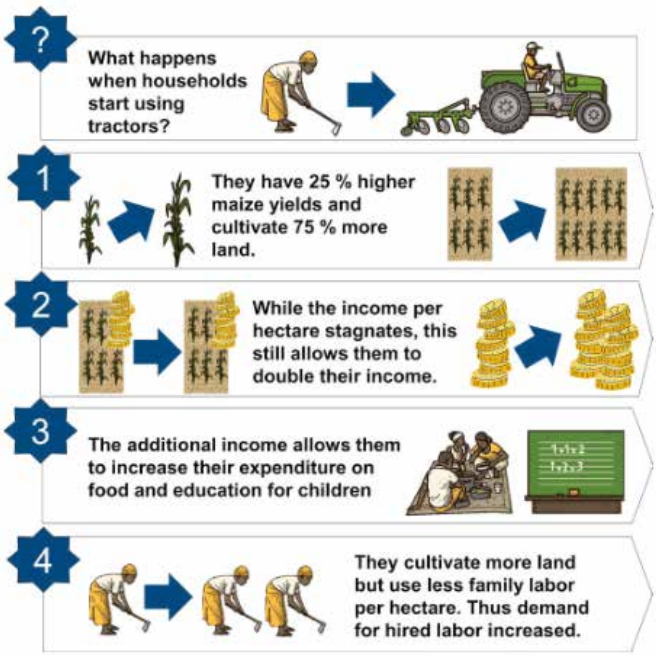
Smallholder production systems in Africa demand locally adapted machinery that aligns with small farm sizes, available skill levels and agro-climatic conditions (Daum and Birner, 2020; Fatunbi and Odogola, 2018). Existing land tenure systems often hinder large-scale agriculture and limit the viability of conventional, large-scale machinery. Historically, government-led mechanization programs failed due to challenges such as a lack of skilled personnel, high equipment costs and limited access to spare parts. More recently, there has been a noticeable trend of importing smaller tractors from Asian countries, particularly in areas where animal traction is ineffective. The choice of technological pathways—whether animal traction, two-wheel tractors, or four-wheel tractors—and the necessary institutions and investments for scaling should be determined by local conditions (Daum et al., 2023c). Efforts to make machinery accessible and affordable for smallholders should focus on building capacity for manufacturing and maintenance while fostering public-private partnerships to ensure long-term sustainability. Moreover, effective mechanization policies and programs must be grounded in location-specific analyses that consider economic, agro-climatic and social factors. Such analyses can help identify appropriate technological and institutional solutions while avoiding potential negative impacts, such as job losses.

Impact of mechanization adoption

The adoption of power-driven machinery in African agriculture has the potential to transform rural areas through agronomic, environmental and socioeconomic benefits, such as poverty reduction, food security and increased productivity. For example, the adoption of tractors has been linked to a 25% yield increase in Zambia and doubled smallholder incomes by expanding cultivated land and improving labour productivity (Adu-Baffour et al., 2019) (see Figure 5). A study across 11 countries found mechanization increased fertilizer use by 13 kg/ha while reducing household labour by 1.6 adult equivalents and reliance on hired labour (Kirui, 2019). However, these benefits depend on local conditions, such as crop types, rainfall and cultural norms, and come with risks like deforestation, soil erosion and gender inequalities. To ensure sustainable outcomes, mechanization strategies must address social, economic and environmental dimensions holistically (Daum et al., 2020a).

Mechanization can make farming more attractive to Africa's youth by reducing the physical burden of agricultural work (Fatunbi and Odogola, 2018). This shift allows individuals of all ages, genders and backgrounds to engage more productively and profitably in farming, making agriculture a more viable and appealing livelihood option. The reduction of physical labour demands through mechanization also has implications for human energy requirements and nutritional outcomes—a link that has been largely overlooked in the literature (Daum

Figure 5: *Impacts of tractor use in Zambia*



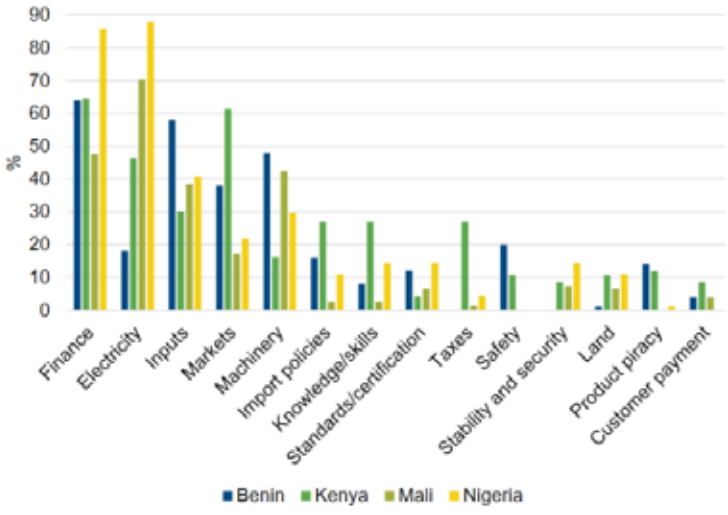
Source: PARI (2020a)

and Birner, 2019; PARI, 2020b). For example, in Zambia, farmers in non-mechanized households reliant on hand-held tools often struggle to meet their dietary energy needs. Men, who typically perform more physically demanding tasks, require between 3,000 and 3,800 calories per day, while women have slightly lower energy requirements. Insufficient caloric intake can limit the time and effort farmers can dedicate to agricultural activities, reducing overall productivity. By saving human energy, mechanization not only enhances farm productivity but also reduces the risk of undernutrition in farming communities.

Local machinery manufacturing

Local agricultural machinery manufacturing is expanding in Africa, but supportive policies and investments are needed to enable local producers to compete with international suppliers (Daum et al., 2023a; PARI, 2022)**.** A cross-country study conducted in Benin, Kenya, Nigeria and Mali on the characteristics, opportunities and challenges of local manufacturers in Africa shows that vibrant local machinery manufacturing markets are emerging across Africa, driven by small but dedicated entrepreneurs who develop machinery adapted to local conditions. However, the sector continues to face challenges (Figure 6). Enhancing the conducive environment for local agricultural manufacturing requires a dual focus on both overarching policies and investments encompassing macroeconomic conditions and infrastructure and sector-specific initiatives targeting knowledge and skill development, with proven models like vocational training combining on-the-job experience and in-classroom teaching showing promise.

Figure 6: *Top 10 business constraints for local machinery manufacturers*



Source: Daum et al. (2023a)

Lessons from India

India provides valuable insights into how supportive policies can scale mechanization in smallholder production systems. Since the mid-20th century, India's smallholder-dominated agriculture sector has undergone a dramatic shift from traditional farming methods to mechanized processes. Today, the majority of farm power in India is derived from mechanized tools such as tractors, diesel engine pump sets, electric pump sets and power tillers. This transformation was driven in large part by the Green Revolution, which created demand for farm machinery, especially for groundwater irrigation (via pump sets) and tractors for various field operations. As of the Input Census data from 2016-17, roughly 52% of farms own and 55% hire farm machinery. While larger farms in India tend to be more mechanized, even small and marginal holdings (less than 2 hectares) have seen significant uptake of farm machinery. Furthermore, India's Custom Hiring Centres (CHCs), which allow farmers to rent machinery on a "pay-per-use" basis, represent a promising model that could be emulated in Africa.

Africa can draw valuable lessons from India's experience in fostering its own agricultural machinery industry. Policy interventions should prioritize reducing the cost of accessing farm machinery for smallholder farmers. India has emerged as the world's largest tractor manufacturer, followed by the USA and China. This achievement reflects key policy changes that facilitated private sector participation and foreign collaborations, transforming India from a net importer of tractors in the 1960s and 1970s to a major exporter. Additionally, creating incentives for private sector investment in local manufacturing, fostering international collaborations and improving access to affordable financing and raw materials will be crucial. By developing local capacity and making farm machinery more accessible, Africa can transition from reliance on imported machinery to a thriving domestic agricultural machinery industry.

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2.5 DIGITALIZATION

KEY TAKEAWAYS

Investments to enhance adoption: Strengthening digital skills, expanding infrastructure and improving the affordability of connectivity are crucial for increasing the adoption of digital technologies in African agriculture, particularly among smallholder farmers.

Integrated platforms: Platforms that offer integrated services and simplify user access hold promise for increasing adoption, but they require sound business models and strategic scaling approaches.

Role of intermediaries: Digital-savvy intermediaries such as extension agents and dealers play a critical role in disseminating information and connecting farmers to DAS, offering a pathway for improved first-mile service delivery.

Data protection: Strengthening data privacy laws, enforcement mechanisms and farmer awareness is crucial as digital services collect increasing amounts of sensitive agricultural data.

The adoption of digital technologies has the potential to significantly increase land and labour productivity in agriculture (Rajkhowa and Baumüller, 2024). **While Africa has seen a remarkable proliferation of digital agricultural services (DAS) in recent years, uptake remains limited.** By 2022, Sub-Saharan Africa hosted more digital agricultural service providers (666) than any other low- and middle-income region globally. These providers primarily offer market linkages or advisory services, while others facilitate financial transactions, supply chain management, or enterprise operations. However, many services remain small and localized, limiting their impact.

Key barriers to the widespread adoption of DAS include a lack of digital skills, poor technology infrastructure, difficulty in locating and using services, affordability issues and an unfavorable policy environment (Kieti et al., 2022). The example of digital tools designed to help smallholder farmers access tractors (sometimes referred to as "uberization") illustrates the influence of broader agricultural challenges on adoption. A study examining such models in Nigeria and India found that while these tools can improve tractor utilization, adoption by farmers is hindered by structural issues like demand concentration during peak seasons and the dispersed nature of rural farms (Daum et al., 2021c; PARI, 2020c). Farmers often prefer analog solutions such as booking agents and phone calls, while tractor owners benefit from digital tools for monitoring and management. Although smallholder farmers may not directly adopt digital tools, they can still benefit indirectly from the increased efficiency these tools bring to service providers.

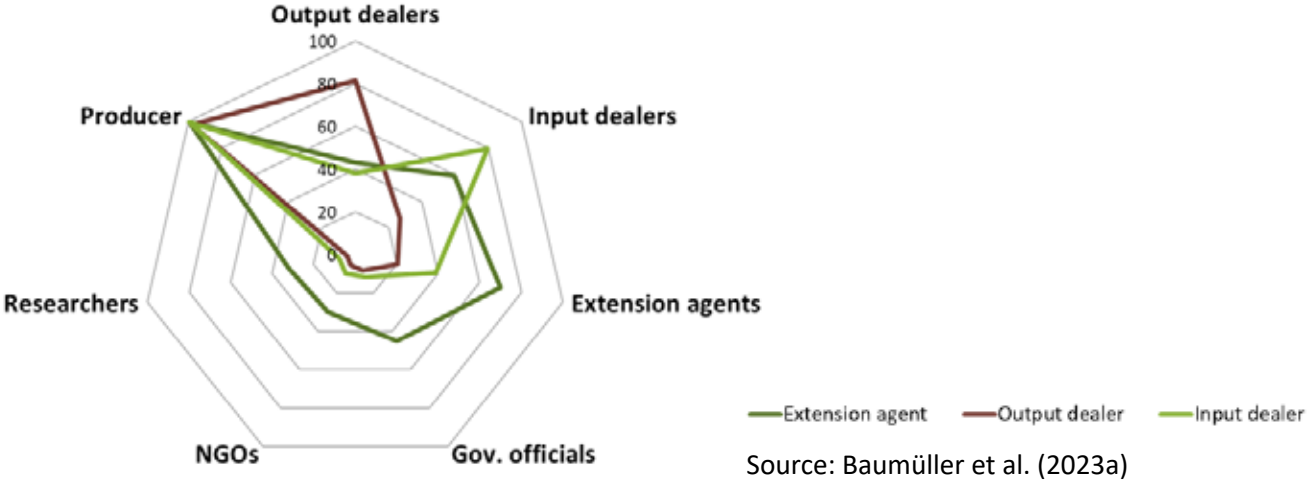
Integrated digital agriculture platforms have the potential to enhance DAS adoption by consolidating various services and making them easier to locate, use and trust. A survey in Kenya found that users are more likely to adopt DAS when platforms guarantee quality and reliability, are accessible to less digitally skilled users and offer comprehensive services across the value chain (Kieti et al., 2021). From the perspective of platform providers, scaling operations involves several strategic decisions (PARI, 2021a). These include developing a business model that balances user benefits with monetization, addressing the "chicken-and-egg" problem of which user group to prioritize first and devising a funding strategy to cover establishment costs and working capital.

Case studies of the digital platforms Twiga Foods in Kenya and AgroMall in Nigeria show how they benefit farmers with assured markets and logistical support while boosting produce supply and business opportunities for buyers. (Baumüller et al., 2024). Platforms like AgroMall, which offer additional services beyond sales, deliver greater benefits to farmers, including higher productivity and income gains. Spillover effects also extend to the wider economy, particularly for input dealers. Digital tools are crucial for coordinating transactions on these platforms. While farmers are not the primary users of these tools, they still benefit from improved market access and reduced transaction costs. In both platforms, intermediaries play a key role in managing the first mile of produce collection from farmers.

Low levels of DAS adoption mask the importance of digital technologies in African value chains. Surveys show that intermediaries like extension agents, output dealers input suppliers widely use digital tools in their work (Baumüller et al., 2023a; PARI, 2023b). Mobile phones, particularly smartphones, are the most commonly used tools. Extension agents rely heavily on digital technologies to interact with various value chain actors, while input and output dealers use them to reduce transaction costs and improve networking and information sharing (Figure 7). Digital marketing platforms could leverage the digital skills and networks of intermediaries to improve service delivery, particularly in covering the first mile from smallholder farmers.

Digital tools also hold promise for improving the collection of data related to food and agriculture. A study in Uganda, for instance, found that SMS-based crowdsourcing of information can be a useful tool to detect changes in food security status over time, thereby providing important data for early warning systems (Baumüller and Kornher, 2024). Another example is the "Time Tracker" app developed in PARI which has demonstrated success in Zambia by reducing recall biases in time-use data collection, revealing that farmers often over-report their working hours (Daum et al., 2021a, 2019). This insight suggests that labour productivity may be higher than previously estimated. Additionally, the app provides valuable data on intra-household labour allocation, offering insights into gender roles in agricultural activities. Future enhancements could include tracking task intensity and user satisfaction.

Figure 7: *Mobile phone-based interactions of agricultural intermediaries with value chain actors*



Source: Baumüller et al. (2023a)

The rise of digital tools collect vast amounts of data from African agricultural producers highlights the need to balance data use with protection. While personal data laws are growing, enforcement remains weak and gaps persist (Chichaibelu et al., 2023). By May 2023, 34 African countries had enacted personal data protection laws (Figure 8). These laws generally align with the basic principles of the 2014 African Union Convention on personal data protection but sometimes fall short in critical areas, such as provisions governing international data transfers and automated decision-making. Enforcement of these laws remains weak and compliance among digital agricultural service providers is limited. Furthermore, agricultural producers often have low awareness of data protection issues and limited knowledge on how to control access to their data. Strengthening data privacy frameworks and their enforcement, while increasing awareness and empowering producers to manage their data, is essential to ensure that digital tools deliver benefits equitably and responsibly.

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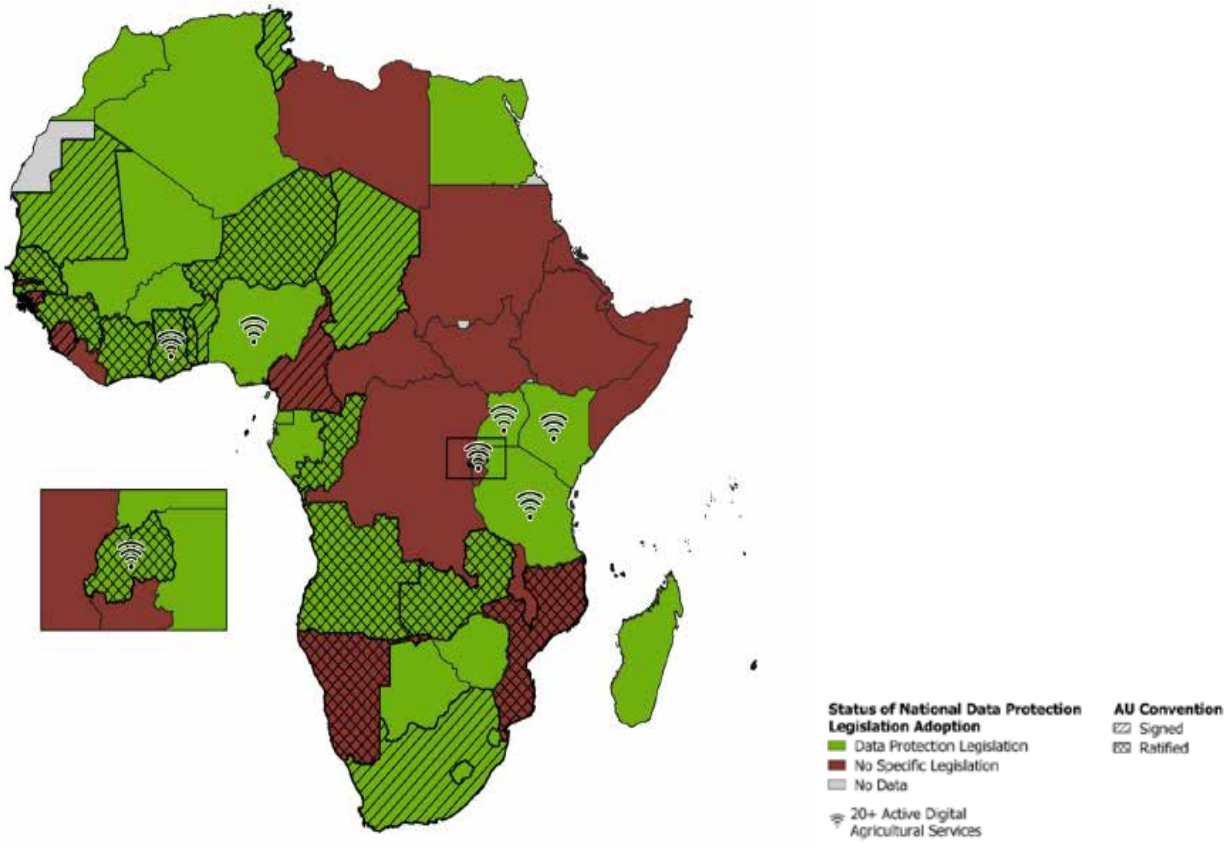
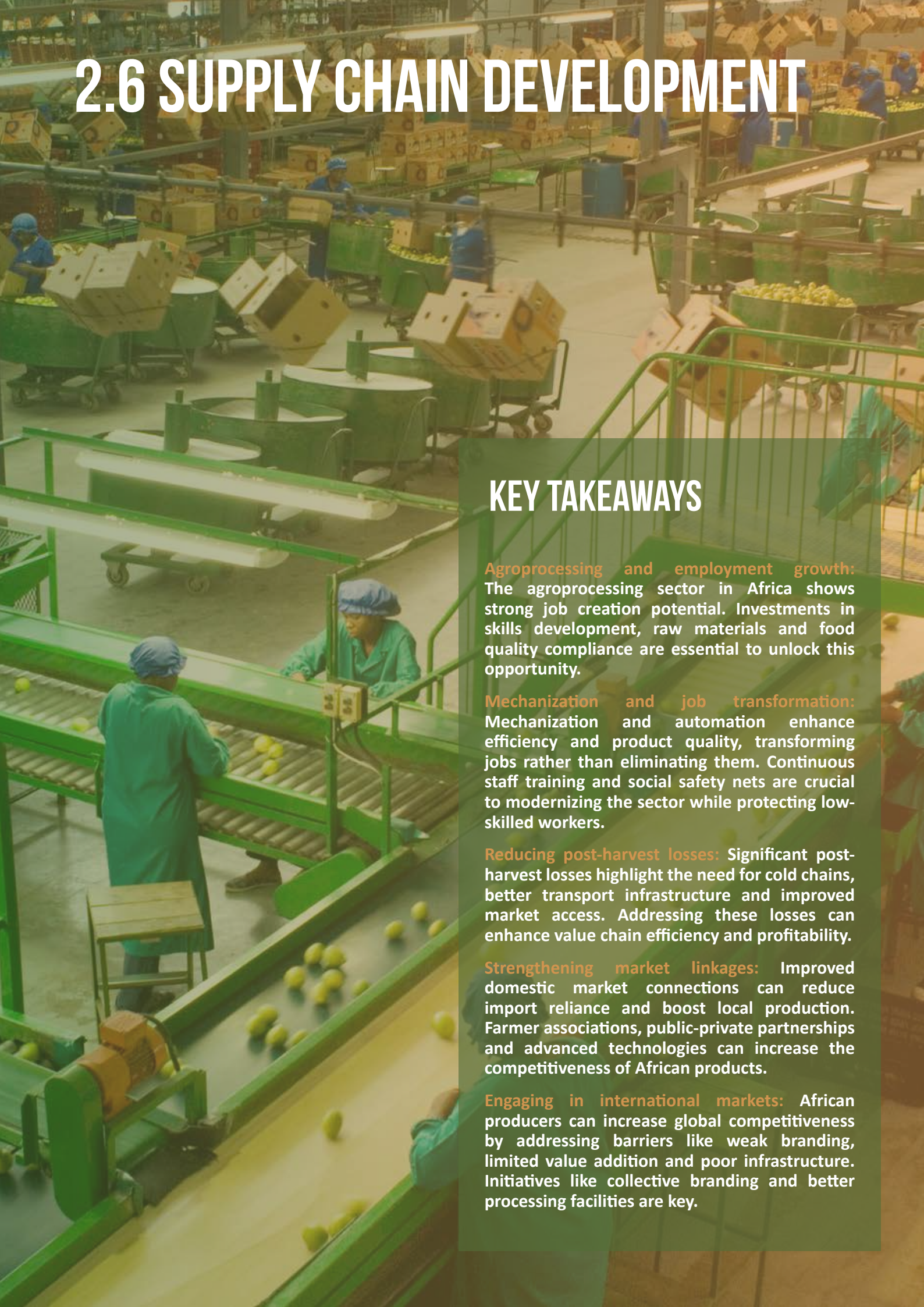
Figure 8: *Status of personal data protection legislation in Africa (as of May 2023)*



Source: Chichaibelu et al. (2023)

2.6 SUPPLY CHAIN DEVELOPMENT



KEY TAKEAWAYS

Agroprocessing and employment growth: The agroprocessing sector in Africa shows strong job creation potential. Investments in skills development, raw materials and food quality compliance are essential to unlock this opportunity.

Mechanization and job transformation: Mechanization and automation enhance efficiency and product quality, transforming jobs rather than eliminating them. Continuous staff training and social safety nets are crucial to modernizing the sector while protecting low-skilled workers.

Reducing post-harvest losses: Significant post-harvest losses highlight the need for cold chains, better transport infrastructure and improved market access. Addressing these losses can enhance value chain efficiency and profitability.

Strengthening market linkages: Improved domestic market connections can reduce import reliance and boost local production. Farmer associations, public-private partnerships and advanced technologies can increase the competitiveness of African products.

Engaging in international markets: African producers can increase global competitiveness by addressing barriers like weak branding, limited value addition and poor infrastructure. Initiatives like collective branding and better processing facilities are key.

Value addition

Employment opportunities in Africa's agroprocessing sector remain largely untapped, but recent rapid growth highlights its potential for significant employment generation (Kubik et al., 2022; PARI, 2024b). A study in Ethiopia, Ghana and Tunisia finds that the formal agroprocessing sector employs between 60,000 and 80,000 people in each country, with the figure increasing nearly fivefold when informal sector employment is included. Currently, employment in agroprocessing accounts for only about 5% of total food economy jobs, but the sector has experienced rapid growth over the last two decades. High employment elasticities of output—0.55 in Ghana, 0.66 in Tunisia and 0.85 in Ethiopia—illustrate the labour-intensive nature of the sector compared to other manufacturing industries. To fully realize the sector's employment potential, investments in skills development, raw material supply chains and compliance with food quality and safety standards are essential.

Mechanization and automation technologies have significantly improved product quality, safety and efficiency in raw material usage within the agroprocessing sector. Investments in infrastructure and skills are needed for further modernization (Baumüller et al., 2023b; PARI, 2023c). A survey of approximately 500 food and beverage manufacturers in South Africa, Kenya, Nigeria and Ethiopia revealed widespread adoption of power-driven machinery among all firms. Nearly half of surveyed companies also use computer-controlled automation technologies. Further modernization requires investments in power infrastructure, access to machines and spare parts, as well as skilled workers to operate and maintain advanced technologies (Figure 9). While technical skills are in high demand, the adoption of automation has also increased the need for soft skills. Women, who are underrepresented in technical professions, could play a critical role in addressing these skill gaps.

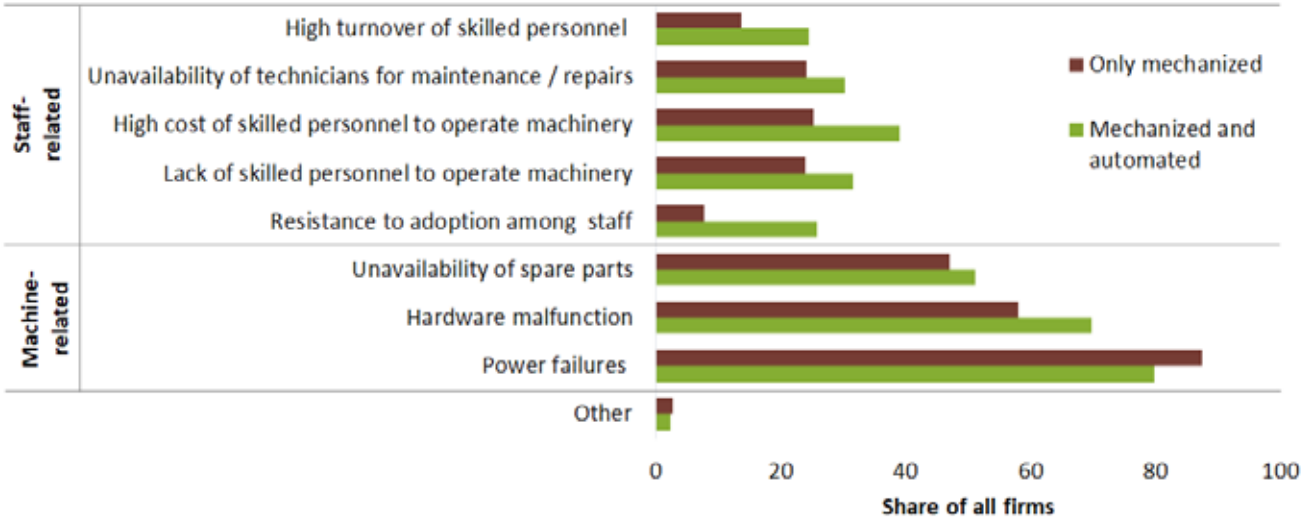
Concerns about automation-induced job losses are common, but evidence from the four surveyed countries suggests that automation is more likely to transform jobs than eliminate them (Baumüller et al., 2023b). After adopting automation technologies, many firms reassigned workers to new tasks instead of laying them off. Where staff changes occurred, they mainly translated into job gains, in particular among medium- and high-skilled staff. Lower-skilled workers may be disproportionately affected, experiencing both job losses and opportunities to upskill for medium- and high-skilled roles. Continuous training programs are needed to build a flexible workforce capable of adapting to fast-changing technologies. Social safety nets should also be established to protect workers who are displaced by modernization efforts.

Post-harvest losses pose a major challenge to the supply of raw materials for value addition which need to be addressed through investments in infrastructure and better access to markets, finance and knowledge for farmers. In Senegal, for instance, an estimated 30% of vegetable production is lost on-farm, translating into $72 million in annual economic losses and reducing vegetable imports by 22% (127,000 tons) if eliminated (Beye and Komarek, 2020). Addressing these losses requires investments in transport and storage infrastructure, adoption of cold chain technologies to preserve perishable produce, improved access to finance for modernizing infrastructure and knowledge dissemination on cold chain management. Vertical integration between producers and distributors could streamline supply chains, improving efficiency and meeting consumer demand more effectively.

Marketing

African countries rely on food imports. In addition to raising productivity, better domestic and intra-African market connections are crucial for local producers to become competitive and benefit from resulting

Figure 9: *Problems encountered by African agroprocessing firms in the use of machinery/automation*



Source: Baumüller et al. (2023b)

opportunities. For example, Ghana imports $450 million worth of rice annually, despite local production (Ampadu-Ameyaw et al., 2018; Omari et al., 2018). Only 20% of domestically grown rice is marketed, largely due to weak market linkages and consumer preference for imported brands. Strengthening the sustainability and profitability of local rice production requires a multi-faceted approach. Linking farmer associations with major distributors or input suppliers could streamline supply chains and reduce costs. Public-private partnerships (PPPs) with milling and processing centers could leverage private sector efficiency alongside public investment. Investments in advanced milling equipment, post-harvest training and branding initiatives would further enhance the competitiveness and appeal of local rice.

Accessing international markets presents additional challenges for African producers, requiring value addition, adherence to export standards and increased consumer awareness. Tunisia, for instance, ranks fourth globally in olive oil production and third in exports, yet struggles with international recognition and market penetration (Zlaoui et al., 2019). The lack of promotional efforts, geographical indications and designation of origin systems limits the visibility of Tunisian olive oil. Additionally, a shortage of processing facilities further constrains value chain growth. To address these issues, establishing exporter consortia for quality assurance, launching a collective mark (e.g., "Olive Oil from Tunisia") and increasing visibility through commercial activities could enhance competitiveness in global markets. More broadly, supporting local producers in meeting export standards, creating attractive branding and improving value chain infrastructure are critical for increasing Africa's presence in international markets. As these efforts progress, African producers will be better positioned to reduce reliance on food imports and enhance their competitiveness both regionally and globally.

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PARI field visit to a Twiga Foods Collection Centre in Kenya

2.7 WOMEN AND YOUTH

KEY TAKEAWAYS

Systemic barriers: Women face unequal land rights, financial exclusion and traditional roles, limiting productivity and income. Access to land, education and financial services is critical.

Unequal time burden: Women perform more unpaid domestic work than men, restricting economic opportunities. Infrastructure and childcare support can help reduce this burden.

Income inequality: Women earn less and lack benefits in agroprocessing. Addressing wage gaps and providing support can improve their working conditions.

Youth aspirations: Many African youth are open to farming if access to technology, rural infrastructure, and diverse income opportunities improve.

Barriers to youth participation, especially for women: Gender inequalities, like male-dominated land inheritance, and challenges such as limited land and resources, deter many young people, particularly women, from pursuing agriculture.

Empowering young agripreneurs: Success requires better-designed youth programs with adequate funding, market-aligned training, and access to education, financial resources, and social networks.

Women

African women in agriculture face systemic disadvantages stemming from gender-related constraints (Njiraini et al., 2018). Several factors contribute to the productivity gap between men and women in African agriculture, including unequal land rights, restrictions on mobility, traditional labour divisions, unequal educational attainment and literacy and financial exclusion. These disparities limit women's ability to fully participate in agricultural activities, negatively impacting their income and productivity. As a result, these constraints undermine food security and contribute to diminished welfare outcomes across the continent.

Unequal access to land remains one of the most significant challenges for women in agriculture, as land is a fundamental agricultural input (Njiraini et al., 2018). Women are often perceived as less efficient farmers because the plots they own are typically smaller and less fertile than those owned by men. Furthermore, women's restricted access to land hinders their participation in decision-making processes, limits their ability to assume leadership roles in their communities and denies them access to economic assets and services that often require land ownership as a prerequisite. These disparities directly harm women's income and agricultural productivity, emphasizing the urgent need to secure land rights for women.

Addressing the productivity gap between men and women also requires tackling unequal access to education and financial services (Njiraini et al., 2018). African women often have limited access to formal and informal educational programs, excluding them from essential training and extension services. This lack of educational opportunities means women are often unaware of or unable to adopt technological innovations critical to improving agricultural productivity. Similarly, women face significant barriers to accessing financial services and are less likely to use them. Consequently, they often resort to low-cost, labour-intensive technologies that are less efficient and insufficient for scaling up along the value chain. Investments in agricultural innovations and technologies tailored to women's needs are essential (PARI, 2020d).

Traditional gender roles further limit women's ability to participate fully in paid work, which affects their income, wealth, access to resources and bargaining power within households and society at large. Time-use data from Ethiopia, Ghana and Uganda shows that women work more hours in total (up to two hours more) and spend significantly more time on unpaid domestic work (up to 6.5 hours more) compared to men (PARI, 2024c). Gendered patterns also extend to children's time use, with girls working up to 1.5 hours more than boys. Improved infrastructure, such as all-weather roads, electricity and piped water in homes, could reduce the domestic burdens on women. However, in the absence of alternative caregivers, reduced time spent by mothers on domestic and care work may negatively affect children's diets (PARI, 2024d; Saleemi et al., 2024). Therefore, it is critical to invest in affordable, high-quality childcare while promoting a more equitable distribution of care work between men and women in households.

Women working in agroprocessing and leather sectors also face significant disadvantages in income and job quality compared to their male counterparts. Evidence from Ethiopia shows that women earn 35% less from primary jobs and 40% less in total income than men (Getahun et al., 2024). This income disparity is partially explained by the "child penalty," where women with children experience greater income gaps due to their inability to engage in moonlighting and overtime work. Women are also less likely to receive job benefits such as housing, discounted or complementary meals, or on-the-job training. Despite these inequities, women report higher levels of job satisfaction and happiness and are more likely than men to rate their working conditions positively. However, this contentment may limit women's aspirations for equal pay and non-monetary benefits. Addressing these gaps requires narrowing differences in human capital and fostering aspiration-building programs to empower women to demand fair pay and better job benefits.

Youth

Rural youth in Africa often pursue off-farm employment, gravitating towards non-farm sectors and migrating to urban areas for better opportunities and improved socio-economic status (Mussa, 2020)providing an opportunity for governments to influence the rural out migration of youth. However, policymakers should also be equally aware that anti-poverty policy measures that simply improve the incomes of rural youth might have unpredictable and unintended consequences on their migration decisions. As a result, policy measures may have to also influence the perceptions of youth toward farming and rural life, and to make rural areas more attractive to the youth. Taking southwestern Ethiopia as a case in point, it was found that above half the adolescents have negative perceptions about farming. Stakeholder insights from Benin, Kenya, Nigeria and Mali echo this trend, reflecting a common perception that farming lacks appeal for the younger generation (Daum et al., 2022a).

Evidence also suggests, however, that many youth remain open to participating in the agriculture sector, provided the conditions are favorable. A study among Ethiopian youth, for instance, shows that many of them consider leaving their hometowns, but only half are firmly committed to out-migrating (Mussa, 2020), offering an opportunity for governments to influence the rural out migration of youth. The binary questions about farming (e.g., full-time farming vs. no farming) often in fact often misleading (LaRue et al., 2021). A study in Kenya shows youth aspire to adopt mixed livelihood strategies, combining on-farm and off-farm income sources. Similarly, in Zambia, while youth are aware of the challenges and opportunities in both farming and urban migration, many still express a desire to engage in farming and stay in their villages, as evidenced by their aspirational drawings (Daum, 2019). Similarly, nearly 40% of youth in Kenya, Liberia, Malawi and Tanzania aspire to work in agriculture and food systems, challenging the narrative of widespread disinterest (Kubik, 2022). Factors related to technology, investment opportunities and decent pay would make agriculture an attractive employment option for young people (Figure 8). Moreover, the average age of African farmers is significantly lower than previously claimed, standing at 34 years, not 60.

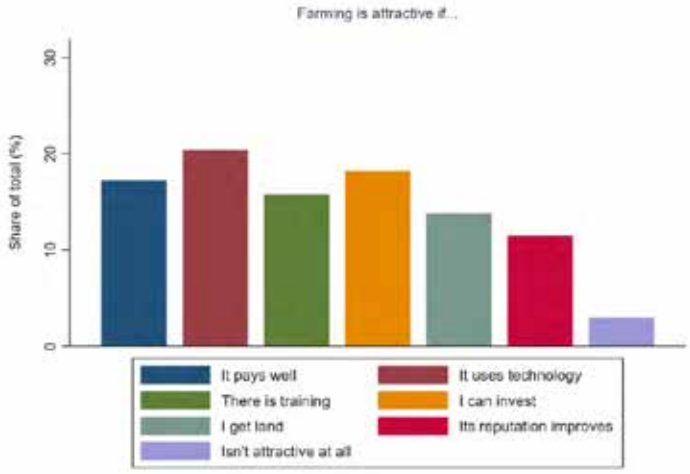
Family plays a pivotal role in shaping youth aspirations. Studies highlight how close family, particularly parents, strongly influence young people's ambitions (LaRue et al., 2021; Ogunjimi et al., 2023). Many parents encourage their children to engage in farming, driven by deep cultural ties to agriculture or the scarcity of non-agricultural employment in rural areas. However, in Zambia, young women are less inclined to pursue farming. This reluctance stems not only from the burden of unpaid family labour but also from systemic gender inequalities, such as male-dominated land inheritance practices, where land rights are passed exclusively from fathers to sons.

Engaging youth in policymaking and aligning policies with their diverse aspirations is crucial. This approach ensures that policies and programs reflect a nuanced understanding of youth aspirations (Daum, 2019; Daum et al., 2022a; LaRue et al., 2021). Additionally, governments should prioritize initiatives to improve access to technology, expand rural infrastructure, support non-farm sector growth (Mussa, 2020) and address gender disparities (Mussa, 2020; Ogunjimi et al., 2023)providing an opportunity for governments to influence the rural out migration of youth. However, policymakers should also be equally aware that anti-poverty policy measures that simply improve the incomes of rural youth might have unpredictable and unintended consequences on their migration decisions. As a result, policy measures may have to also influence the perceptions of youth toward farming and rural life, and to make rural areas more attractive to the youth. Taking southwestern Ethiopia as a case in point, it was found that above half the adolescents have negative perceptions about farming (both farming life and the pre-requisites to become a farmer. Such measures can encourage youth, particularly young women, to participate in commercial farming or even pursue full-time farming careers.

Several factors can make jobs in the food system more appealing to youth, including technological advancements, investment opportunities, market access and decent wages (Kubik, 2022). Surveys of young agripreneurs in Ethiopia, Tunisia and Benin reveal that most youth involved in the agriculture and food sectors do so out of choice rather than necessity (Adegbola et al., 2022a; Nigus et al., 2022; Zlaoui et al., 2022). Key success factors for these agripreneurs include formal education, hands-on experience, access to financial resources and leveraging social networks (Figure 10). However, common challenges—such as inconsistent raw material supply, price volatility, limited customer bases and restricted access to land and machinery—must be addressed through targeted policies and investments.

Participation in youth employment programs could significantly improve job prospects for young people across African countries, but their impact has been mixed. While such programs aim to create employment opportunities and provide skill development and entrepreneurship training, issues such as limited access, duplication of efforts and poor design and implementation undermine their effectiveness. Challenges include insufficient funding, inadequate monitoring and a lack of reliable data (Ampadu-Ameyaw et al., 2020; Getahun and Fetene, 2020a; Gondwe et al., 2020; Zlaoui et al., 2022). To improve outcomes, better coordination among programs and between public and private sectors is needed, along with standardized monitoring and evaluation indicators. Addressing skill mismatches is another critical challenge. The skills taught in many programs often fail to align with market demands. Integrating entrepreneurship training into school curricula, with a focus on agriculture, could help build a skilled workforce. Furthermore, offering incentives to private sector actors to hire youth could create additional job opportunities.

Figure 10: *Factors that make farming attractive according to rural youth in Africa*



Source: Kubik (2022)

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2.8 SKILL DEVELOPMENT

KEY TAKEAWAYS

Agricultural extension services: Extension services can boost the adoption of farming technologies (in particular fertilizer and improved seeds), reduce food shortages and enhance dietary diversity.

ATVET reform: African vocational training lack practical training and alignment with private sector needs. Investments in digital technologies, upgraded facilities and hands-on curricula are essential to prepare youth for modern agriculture.

Sustainability in education: Agricultural education in Africa needs stronger integration of sustainability topics. Barriers like limited materials and weak stakeholder connections must be addressed to enhance impact.

Lessons from India: India's focus on entrepreneurship, grassroots knowledge and industry linkages offers a model for enhancing ATVET programs and boosting agricultural productivity in Africa.

Extension services

Agricultural information and extension services play a vital role in facilitating the adoption of farming technologies and improving food and nutrition security. For example, a study in Ethiopia found that wheat and barley farmers were more likely to adopt modern inputs, such as chemical fertilizers and improved seeds, when they received information through community gatherings and on-farm advisory services (Ahmed and Getahun, 2019). In contrast, demonstration plots were found to be ineffective due to their limited availability and restricted number. Another study revealed that extension services had a stronger impact on the adoption of inputs, like improved seeds and fertilizers, compared to sustainable and labour-intensive technologies such as irrigation, soil conservation, or organic fertilizers (Getahun and Fetene, 2018). Furthermore, evidence shows that agricultural extension services reduce summer food shortages and improve household dietary diversity.

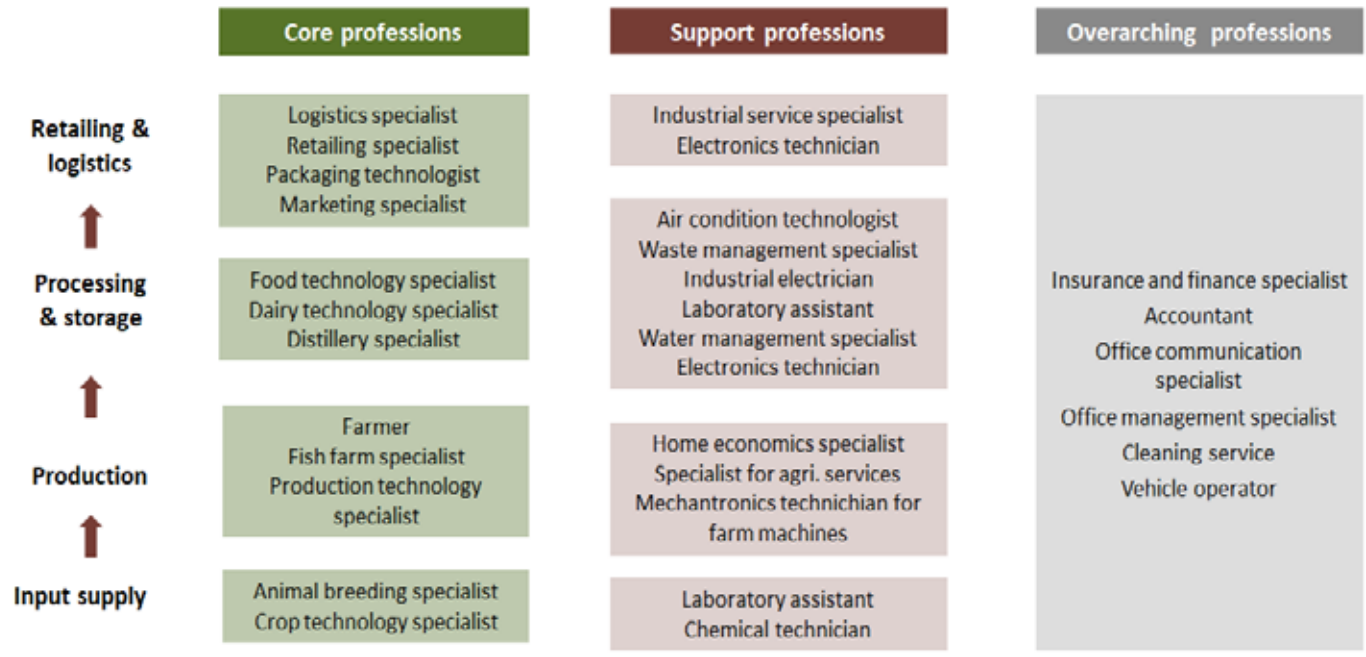
Agricultural information and extension services play a crucial role in facilitating the adoption of modern farming technologies and improving food and nutrition security. For instance, a study in Ethiopia found that the adoption of modern inputs, such as chemical fertilizers and improved seeds, by wheat and barley farmers in Ethiopia was positively influenced by information received through community gatherings and on-farm advisory services (Ahmed and Getahun, 2019). Conversely, demonstration plots were deemed ineffective in promoting the adoption of modern inputs due to their limited availability and restricted number. Another study showed that extension services had a stronger influence on the adoption of modern inputs, such as improved seeds and fertilizer, compared to the adoption of sustainable and labour-intensive technologies, such as irrigation, soil conservation or organic fertilizer (Getahun and Fetene, 2018). Additional evidence underscores the favorable effects of agricultural extension services on reducing food shortages during the summer and improving the Household Dietary Diversity Score within households. These findings highlight the indirect yet significant role of agricultural extension services in enhancing food and nutrition security in rural areas.

Vocational training

Agricultural Technical Vocational Education and Training (ATVET) is vital for building the necessary skills to enhance productivity, product quality and safety, mechanization and sustainable farming, but opportunities in Africa remain limited (Kirui and Kozicka, 2018)**.** A review of ATVET in selected Sub-Saharan African countries indicates that training opportunities for youth are insufficient and often fail to meet the needs of the private sector or local administrations. ATVET programs tend to focus primarily on skills at the production level while neglecting other professions that are essential for well-functioning value chains (Figure 11). They also often lack adequate practical components. To meet the demands of increasingly commercial and technical agricultural systems in the 21st century, ATVET must undergo significant reform. One potential model is the German dual system, which combines theoretical education with practical training.

Mechanization training programs should prioritize hands-on learning experiences to enable graduates to operate and maintain complex machinery. Despite the availability of ATVET programs, several issues hinder the development of necessary skills. Research in Benin, Kenya and Mali highlights the need for improved curricula, particularly at the university level, with greater emphasis on practical training rather than theoretical concepts

Figure 11: *Core, support and overarching professions along the agricultural value chain*



Source: Kirui and Kozicka (2018)

(Adegbola et al., 2020b; Kergna et al., 2020; Makini et al., 2020b). Additionally, investment is needed to provide more machines and tools for students, upgrade mechanical workshops and renovate training centers and classrooms.

Agricultural training curricula at universities and vocational training institutions should also place greater emphasis on sustainability-related topics. A survey of teachers and students in Benin, Kenya, Mali and Nigeria revealed that agricultural education in Sub-Saharan Africa addresses a wide range of environmental, social and economic issues (Yameogo et al., 2024). Teachers possess advanced degrees in various sustainability topics, providing a strong foundation of expertise within agricultural institutions. Nevertheless, challenges remain in mainstreaming sustainability into course curricula. Structural barriers, such as limited access to relevant course materials and weak linkages between agricultural education institutions and other stakeholders in the agricultural innovation system, would need to be addressed to enhance the sustainability and impact of agricultural education.

Lessons from India

India offers valuable insights into improving ATVET, emphasizing entrepreneurial skills, grassroots knowledge, stronger industry linkages and practical training (Ganguly et al., 2019)**.** Skill development has become increasingly important in India due to its large youth population, growing workforce and potential for enhancing sectoral productivity. While ATVET programs have been in place for some time, they have struggled to attract youth and have had limited impact in fostering aspirational career pathways or innovative entrepreneurial spirit. These shortcomings stem from poor program quality, limited outreach and the absence of robust monitoring and evaluation frameworks.

To address challenges in the ATVET system, skill development programs—whether part of vocational or formal education—should prioritize innovation and entrepreneurship (Ganguly et al., 2019)**.** Programs should also integrate practical, home-grown practices that are passed down through generations. Strengthening firm-farm linkages and providing on-the-job training in sectors like food processing could enhance practical learning experiences. For long-term success, skill development programs must be sustainable and financially viable. This includes designing demand-driven programs linked to job opportunities across various sectors. By focusing on these strategies, African countries can create skill development systems that inspire innovation, attract youth and improve the overall productivity and sustainability of the agricultural sector.

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2.9 INFRASTRUCTURE

KEY TAKEAWAYS

Targeted infrastructure investments: Integrated investment plans tailored to local conditions that combine different infrastructure types and include skills training are key to creating jobs and boosting incomes.

Boosting yields with affordable water solutions: Small-scale irrigation, combined with technologies like solar pumps and rainwater harvesting, can increase productivity and climate resilience. However, adoption requires addressing barriers like water scarcity, land tenure, water rights, and credit access.

Lessons from Kenya's drip irrigation: Success depends on strong community engagement, water management training, and institutional support to sustain long-term benefits.

Expanding energy access: Investments in infrastructure, subsidies, and financial support, as seen in India and Ethiopia, are critical for adopting modern energy solutions and improving rural livelihoods.

Solar integration in agriculture: Solar power can reduce food waste, enable irrigation, and offer dual income streams, but success relies on subsidies, affordable credit, and sustainable water management.

Irrigation

Evidence from Mali and Niger shows that small-scale irrigation can boost yields and strengthen climate resilience. Despite rising adoption, targeted investments and supportive institutions are needed to scale these systems effectively (Olayide et al., 2020). Studies demonstrate that small-scale irrigation can significantly increase productivity in the region, but adoption is often constrained by water scarcity and competing demands for water. Investments in irrigation must consider environmental, economic and social factors to ensure long-term sustainability. In regions where water is a limiting factor, adopting water-saving technologies and implementing groundwater monitoring frameworks can help preserve this valuable resource. Institutional arrangements are also critical for reducing implementation costs and ensuring the equitable and sustainable use of water. To unlock the full potential of irrigation, it must be combined with other yield-enhancing measures. A pan-African study revealed that when supplementary irrigation is used alongside fertilizers and improved seeds, maize yields can more than double, with yield gains ranging from 1.2 to 2.9 tonnes per hectare depending on the country and scenario (PARI, 2018; Rezaei and Gaiser, 2017) (Figure 4).

In Africa's smallholder production systems, small-scale irrigation can play a vital role in mitigating economic water scarcity. Limited water access during the dry season significantly restricts agricultural productivity in Sub-Saharan Africa (SSA), where only 4% of the land is irrigated. This is primarily due to economic water scarcity, characterized by insufficient investments in water resource management and farmers' limited financial capacity to harness available water resources. Small-scale irrigation systems offer an affordable, manageable solution that can be adapted to diverse farming systems (Koo et al., 2019). Examples of such technologies include rainwater harvesting, flood recession irrigation, floodwater spreading, river diversion, treadle pumps, motor pumps, solar-powered pumps and porous jars.

The suitability and expansion potential of small-scale irrigation technologies vary depending on regional conditions (PARI, 2019d). Across Africa, the potential for small-scale irrigation development spans 7.3 million hectares, with individual countries' potential ranging from 0 to 2.5 million hectares based on factors such as surface-water runoff availability, on-farm investment costs, crop mix and market accessibility. For instance, motor pumps and treadle pumps have the highest area expansion potential. However, their reliance on groundwater poses environmental risks, including over-extraction, especially in drought years. Conversely, communal river diversion and small reservoirs, while offering lower expansion potential, are better suited to reaching rural populations. To ensure sustainable small-scale irrigation expansion, policies should address critical issues such as land tenure, water rights and access to credit.

Insights from a small-scale irrigation project in Kenya further illustrate the importance of both technological and institutional innovations for the successful and sustainable adoption of irrigation systems (Makini et al., 2020c). The Smallholder Drip Irrigation Project in Kibwezi, Kenya, constructed comprehensive infrastructure, including drip lines, filtration and fertigation chambers and pump houses, providing households with one acre of drip-irrigated land. The project delivered immediate benefits, such as increased income and improved livelihoods due to enhanced crop and livestock production. However, these gains were short-lived because of poor water management and limited community engagement during the project's implementation. To sustain such benefits, active community involvement, adequate training for beneficiaries on water management and irrigation-based crop production and the establishment of a water management committee are needed.

Energy

Expanding reliable energy supply—both centralized and decentralized—will require supportive measures, including infrastructure investments, access to finance and greater dissemination of information. Lessons from India illustrate how the adoption of photovoltaic (PV) installations accelerated after a significant reduction in capital costs in 2010 (Gulati et al., 2016). For large-scale adoption, additional investments in transmission infrastructure, such as batteries and pumped storage systems, will be necessary. Financial assistance has also been shown to play a crucial role in the adoption of modern energy solutions. For instance, in Ethiopia, subsidizing the price of biogas digesters by 10% significantly improved household livelihoods. The subsidy enabled families to redirect labour previously used for fuelwood collection to agricultural activities, thereby boosting household income (Lokonon et al., 2023). Other key factors influencing the adoption of modern energy solutions include increased exposure to new technologies and better access to information (PARI, 2019).

The example of Kenya's dairy value chain highlights the efficiency gains achievable through the adoption of solar-powered technologies (Salvatierra Rojas et al., 2018; Torres-Toledo et al., 2018). In Kenya, small-scale dairy farmers producing approximately 1-10 liters of milk daily collaborate through cooperatives to address challenges associated with their limited production capacity. These cooperatives collect and distribute raw milk to larger markets. However, significant milk losses—estimated at 20-30%—occur due to issues such as inadequate hygiene practices, the lack of cooling systems and high microbial contamination. To tackle these challenges, PARI introduced a solar milk cooling system, originally developed in Tunisia (Figure 10). This innovative technology utilizes solar power to produce ice, which is then used to preserve milk quality in specially designed cans. Adapted to Kenyan conditions, the system proved capable of reliably supplying ice year-round and effectively preserving milk quality from farm to market. By reducing spoilage and improving milk hygiene, the solar-powered cooling system enhanced Kenya's dairy value chain while offering a sustainable and clean energy solution for off-grid rural environments.

Integrated infrastructure investments

To maximize the benefits of infrastructure expansion, integrated investment plans are essential. These plans should be tailored to local circumstances, capitalize on complementarities between different types of infrastructure and generate employment opportunities. A comparative study of Niger and Côte d'Ivoire demonstrates the varying impacts of infrastructure investments depending on initial conditions (Sangare et al., 2024). In Niger, where the coverage of basic water and electricity services is minimal, additional

investments in these infrastructures have the greatest potential for creating jobs. Conversely, in Côte d'Ivoire, investments in road infrastructure are more effective in driving employment growth. A significant proportion of the jobs created in both countries are in the construction sector, with additional employment opportunities arising in agriculture, trade and food processing. Aligning infrastructure investment strategies with skills development to better harness the job-creating potential of their development initiatives.

The example of India underscores the importance of adopting integrated strategies that not only leverage complementarities between different types of infrastructure investments but also align them with broader policy objectives (Gulati et al., 2016). The Indian government has set ambitious goals to scale up solar power installations and increase farm incomes—objectives that are complementary in many respects. The declining cost of solar power, coupled with agricultural innovations that boost productivity, creates a unique opportunity to achieve both goals simultaneously. Integrating solar energy into agriculture, for example, offers dual benefits. Installing solar panels at a height of 15 feet above agricultural fields enables food crops to grow beneath them, providing farmers with two income streams. Solar power can also be used for irrigation, replacing electric pumps with solar-powered ones. This transition could reduce energy subsidies, freeing up resources that could be redirected toward subsidizing solar pump purchases. Incorporating solar power into cold chains is another innovative avenue. This integration could expand the use of solar energy while simultaneously reducing food waste. However, for these initiatives to succeed, financing remains a critical challenge, such as providing upfront subsidies, facilitating access to low-interest credit and designing financial instruments that lower the entry barrier for farmers. Policies must also address sustainability concerns, particularly regarding water resources.

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Figure 10: *Solar milk cooling components incl. insulated milk cans, PV modules and freezer*

Source: Salvatierra Rojas et al. (2018)

2.10 SUSTAINABILITY, CLIMATE RESILIENCE AND BIODIVERSITY

KEY TAKEAWAYS

Agroecological practices: Agroecological practices can improve land productivity in African smallholder farming, especially when combining organic and mineral fertilizers, though their effectiveness depends on specific practices, crops and local conditions.

Carbon farming: Carbon farming can address food insecurity and reduce emissions, but requires training in implementing related practices, cost-effective carbon monitoring and stronger farmer organization support.

Sustainable livestock: Livestock policies often overlook environmental, social and health trade-offs, such as GHG emissions and unequal socio-economic benefits. Integrated, multi-stakeholder approaches are needed to ensure livestock development aligns with sustainability goals.

Climate change impacts: Climate change reduces crop yields, livestock productivity and food security in West Africa, while extreme weather worsens nutrition and health risks for vulnerable groups.

Building resilience: Strategies like drought-tolerant crops, agroforestry and early warnings, supported by participatory policies and funding, are essential for drought resilience and long-term sustainability in the Sahel.

Sustainable production methods

Agroecological practices could boost productivity in African smallholder farming systems, particularly through the combined use of organic and mineral fertilizers, but impacts will vary by the context in which they are applied (Romero Antonio et al., 2024). Agroecological practices have long been incorporated in African farming systems, even if the term was not explicitly used, such as intercropping, integrated crop-livestock systems and the use of organic fertilizers. A meta-analysis exploring possible effects of agricultural practices on land and labour productivity in Africa finds that agroecological practices are associated with positive and significant differences in land productivity compared to monocropping systems—especially monocrops grown without inputs. However, the extent and direction of yield improvements vary depending on the specific practice, crop type, climatic conditions, soil properties and the type of control used. The application of organic fertiliser, in particular if combined with even small amounts of mineral fertilizer, showed most consistent yield gains. Evidence on labour productivity, however, remains scarce. The limited studies available suggest that while agroecological practices may require more labour, they can also result in higher profits, such as increased yields or additional income from intercropped legumes.

Carbon farming is emerging as a promising solution to address food insecurity while reducing greenhouse gas (GHG) emissions, but obstacles related to financing, skills institutional arrangements and monitoring could hinder widespread adoption (Schilling et al., 2023)**.** By promoting agricultural practices that enhance carbon sequestration, mitigate GHG emissions and boost agricultural productivity, carbon farming offers a pathway toward sustainability. Despite its potential, financial constraints faced by smallholder farmers remain a major challenge. High transaction costs—such as those related to developing baselines, certification and administration—pose significant barriers to cost-effective carbon farming initiatives. Strengthening the institutional capacity of farmer organizations is therefore critical to overcoming these challenges.

The success of agricultural carbon markets also relies on the accurate measurement and monitoring of carbon stock changes in both soils and biomass (Schilling et al., 2023). Currently, the most reliable approaches for verifying soil carbon sequestration depend on laboratory methods, which are often costly and inaccessible. To advance carbon farming, further research is needed to develop accurate yet cost-effective tools for monitoring carbon sequestration, reducing GHG emissions and verifying the avoidance of emissions. Implementation research is also required to explore institutional arrangements that can facilitate carbon credits and support sustainable production methods in Africa.

Biochar and compost production stand out as valuable interventions within the carbon farming framework (Okyere and Kornher, 2023). Policymakers should consider supporting training programs for farm households to promote the production and use of soil carbon resources like biochar and compost. For example, findings from Ghana indicate that such training initiatives can increase agricultural productivity while simultaneously improving welfare outcomes. Therefore, promoting training programs focused on soil carbon resource production could enhance livelihoods while contributing to climate change mitigation.

Greater attention is needed to ensure the sustainability of livestock production. Insights from Kenya, Zambia and Burkina Faso reveal that sustainability trade-offs are not sufficiently reflected in livestock policies (Kariuki et al., 2022). While all three countries have committed to livestock development through dedicated policies and programs, key trade-offs—such as adverse environmental impacts, uneven distribution of socio-economic benefits between men and women and negative nutritional outcomes—are often overlooked. Specifically, policy documents pay limited attention to issues such as GHG emissions, water pollution and the negative health implications of consuming animal-sourced foods. To address these blind spots, an integrated and multi-stakeholder approach is needed in policy-making processes. Such approaches would help identify and mitigate environmental, social and health-related trade-offs, ensuring that livestock policies contribute to sustainable development goals without compromising other critical areas.

Climate change and resilience

Climate change significantly affects food security in West Africa in diverse and complex ways (Mbaye et al., 2021). It impacts food availability by reducing crop yields and livestock productivity, while shifting agricultural potentials profoundly influence crop and livestock choices, thereby altering local food value chains. For many net food-buying households in the region, declines in crop yields and livestock productivity often lead to reduced access to food due to rising food prices. Moreover, the increasing frequency of extreme weather events—such as heatwaves, droughts and floods—continues to destabilize West African food systems. These weather extremes exacerbate existing food safety and nutritional security challenges, posing particularly severe risks to the most vulnerable social groups. Additionally, changing climatic conditions are projected to facilitate the spread of infectious diseases, further undermining nutritional security and human health in the region.

In response to the interlinked threats of climate change and land degradation, numerous innovative solutions are being tested and deployed across West Africa (Mbaye et al., 2021; Mirzabaev et al., 2021). Mitigation strategies include irrigation, rainwater harvesting, crop diversification, the adoption of drought-tolerant crops, conservation agriculture, agroforestry and rational grazing practices. Complementary policies—such as carbon trading, land-use zoning, payment for ecosystem services and empowering women—align with these efforts to promote sustainability and resilience. A conflict-sensitive approach, however, is critical to ensure that these initiatives do not exacerbate existing tensions in the region. Local solutions integrate tested climate change adaptation and sustainable land management practices should be prioritized. For these strategies to be effective, policies must set achievable objectives, secure adequate funding and implement robust monitoring systems. Sustained focus on these challenges post-COVID is essential to prevent a diversion of resources and priorities away from critical development needs in the Sahel.

The impact of drought is of particular concern in the Sahel, given its devastating effects on livelihoods. A survey of key

experts across public, private and societal sectors indicates that rural households in the region commonly respond to drought by adopting sustainable agricultural practices, migrating, diversifying income sources and relying on social networks (Boukary et al., 2023). To strengthen drought resilience in the Sahel, several key actions are needed, including disseminating climate-friendly agricultural practices supported by robust monitoring and evaluation systems, providing timely information on early drought warnings and preparedness measures and mobilizing financial resources to implement policies aimed at building drought resilience. Moreover, drought policies should be participatory, results-oriented and informed by long-term forecasting to ensure sustainability and resilience. By integrating these elements into policymaking, the Sahel region can better prepare for and mitigate the impacts of future droughts.

Biodiversity

Agrobiodiversity is essential for the sustainability and resilience of agrifood systems. Contrary to common perception, evidence from Burkina Faso and Ghana suggests that the number of crop varieties has actually increased in recent years in the surveyed villages (Ademilola et al., 2024). This positive trend can largely be attributed to socio-economic factors such as market demand, yield potential, market value, irrigation schemes, migration and government initiatives. Certain crops, such as bambara groundnut, sorghum and millet, are cultivated not only for their economic value but also for their cultural significance. Findings from the case study villages indicate that "not all is lost" with respect to agrobiodiversity: while crop and varietal diversity is increasing in some parts of Africa, it is declining in others. To further enhance the conservation of crop and varietal diversity, policymakers and stakeholders should leverage the identified economic drivers and cultural factors. Incorporating farmers' preferences and values into policy frameworks is particularly critical to ensure that conservation efforts align with economic incentives and the practical realities of agricultural production.

Strategies aimed at promoting biodiversity-smart farming systems must reconcile biodiversity conservation with the need to improve land and labour productivity (Daum et al., 2023b). Farmers are often motivated to adopt labour-saving technologies, even when these have adverse effects on biodiversity (e.g., mechanization or pesticide use). Conversely, labour constraints may prevent farmers from adopting biodiversity-enhancing practices that increase labour intensity, such as intercropping or planting basins. Addressing these trade-offs is essential to balance agricultural productivity growth with biodiversity conservation. One promising approach is scale-appropriate mechanization, where machinery is adapted to the size of farms rather than forcing farmers to adapt to large-scale equipment. Examples include the use of draught animals, small tractors and two-wheeled tractors, which are already common in parts of Asia and some regions of Africa. Additionally, innovations such as mechanized conservation agriculture, agricultural robotics and precision spraying could further enhance productivity while minimizing negative impacts on biodiversity

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2.11 INSTITUTIONS AND POLICIES IN FOOD AND AGRICULTURE

KEY TAKEAWAYS

Strengthening farmer organizations: Transparent and well-structured farmer organizations focusing on high-value crops achieve stronger outcomes. Pooling resources and investing in technology further boost productivity and reduce poverty.

Innovation platforms for impact: Collaborative innovation platforms enhance food security and incomes by fostering partnerships, driving technology adoption, and improving agricultural practices, as demonstrated in successful initiatives across Kenya, Zambia, and Benin.

Innovation as a coping strategy: Low innovation levels in African firms are often reactive, addressing challenges like power outages and limited financing, rather than proactively enhancing competitiveness.

Fostering innovation ecosystems: Strengthening innovation ecosystems through improved access to finance, raw materials, markets, and tailored strategies—such as modernization and value chain integration—can drive growth and success.

Attracting FDI: Strong agricultural sectors, growing domestic consumer markets and public investments are essential to attract FDI, with market potential being key for least-developed countries.

India-Africa learning: Comparisons between Indian states and African countries show that integrated investments in agriculture, education, and social protection boost economic growth, food security and nutrition, with a focus on efficient spending in research and infrastructure.

Farmer organisations

Farmer organizations (FOs) in Africa play a vital role in improving productivity and connecting farmers to markets. However, many FOs face significant financial and organizational challenges that limit their capacity to support their members (Kampmann and Kirui, 2021)**.** Interviews with FOs in Senegal, Uganda and Zambia reveal that nearly all FOs are heavily reliant on external resources, with member contributions accounting for only about 5% of their annual budgets. At the same time, evolving agricultural policies have increasingly shifted responsibilities—such as agricultural education, marketing and the provision of farm inputs—onto FOs, roles traditionally handled by governments. Many FOs are ill-equipped to handle these responsibilities due to limited skills, weak organizational structures and severe resource constraints. As a result, some FOs are undermined by attempting to take on too many roles and overly ambitious objectives, including the provision of public goods.

To enhance their effectiveness, FOs need revitalization through capacity-building for leaders, expanding membership bases, increasing financial contributions and creating opportunities for regular engagement with policymakers (Kampmann and Kirui, 2021). Governments should involve FOs in decision-making bodies on agricultural, food and rural development issues. Additionally, programs to encourage members to contribute financially to their FOs are crucial. Strategies could include strengthening farmer-driven cooperatives, promoting innovation and training and creating value addition through agricultural processing.

A study conducted in Burkina Faso and Kenya highlights institutional factors within FOs that drive positive outcomes for their members (Wortmann-Kolundžija, 2019). FOs with efficient internal structures, well-functioning group activities and strong social connectedness were more likely to provide better support to their members. Members also tended to participate more actively in smaller FOs with transparent structures. The purpose of the FO also played a significant role: marketing cooperatives that focused on higher-value crops and products generated more revenue and had a greater positive impact on members' incomes than production cooperatives. Furthermore, FOs were more successful when they built trust and fostered an entrepreneurial mindset among their members.

Farmer groups can also enable members to invest in their farms by facilitating access to finance and technology. For example, Nigeria's National Fadama Development Project formed groups to help farmers obtain credit and productive assets (Philip et al., 2018; Phillip et al., 2018a). By pooling resources, farmers collectively purchased equipment and set aside 10% of net sales for asset maintenance. This collaborative approach led to increased incomes and reduced poverty. Tools such as sprayers, wheelbarrows and cassava lifters were acquired for cassava farming, while rice farmers invested in water pumps, milling machines and threshers. Supported by the World Bank and local governments, this initiative was scaled up across all 36 states in Nigeria.

Innovation platforms

Innovation platforms (IPs) are a strategy to enhance food security and incomes by fostering collaboration among stakeholders with shared interests. Similar to extension services, IPs facilitate the exchange of knowledge and innovative practices, accelerating the adoption of advanced agricultural technologies that improve productivity. In Kenya, members of IPs were reported to have higher adoption rates of innovative technologies and better management practices, which in turn improved food security, food diversity and income levels (Makini et al., 2018b). A notable example in Zambia demonstrates how an IP successfully addressed vitamin A deficiency by promoting the biofortification of maize through collaborative efforts among various stakeholders (Chomba et al., 2018). The government's support for this initiative helped foster widespread adoption of biofortified maize varieties. In Benin, the Multi-Stakeholder Platform (MSP) positively influenced rice production and farmers' incomes in South-West Benin (Adegbola et al., 2017b). Established by the Africa Rice Center (AfricaRice), the National Agricultural Research Institute of Benin (INRAB) and local farmer organizations, the MSP facilitated collaboration across the rice value chain, integrating research, technology transfer and adoption.

Innovation and business environment

Innovation levels among African firms are generally low, but with significant variations across countries. Firms tend to innovate not to improve competitiveness but as a means of navigating and overcoming business challenges (Tadesse et al., 2022)**.** For example, firms in Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Rwanda, Senegal, Zambia and Zimbabwe exhibit low levels of innovation overall. However, innovation is relatively higher in Kenya, Ghana and Zimbabwe. Larger and publicly listed firms were found to be more innovative than smaller, unlisted firms. Interestingly, firms facing obstacles such as power outages or limited access to finance were more likely to innovate, highlighting that innovation often arises as a coping strategy rather than a competitive pursuit.

To boost innovation, businesses need a supportive environment. Insights from East African food-sector start-ups highlight the need to improve access to finance, a reliable supply of raw material and good market connections (Nyangau et al., 2024). Raw material shortages and weak supply chains hinder firms ability to operate at full capacity. Additionally, a lack of specialization among ecosystem players limits the support available to entrepreneurs. Recommendations include fostering collaboration between national research institutions, universities and international partners to translate knowledge into innovations. Providing sector-specific expertise and incentives for start-ups and innovation hubs will also help build a more inclusive and resilient innovation ecosystem.

Case studies of private poultry businesses in Kenya, Nigeria and Senegal underscore the importance of tailoring interventions to specific contexts. In Kenya, modern mechanized production methods, genetic resource imports and enhanced biosecurity measures have driven success (Ilatsia et al., 2022). In Nigeria,

technological advancements, access to investment capital and coordinated value chain strategies have been pivotal (Sonaiya et al., 2022). Meanwhile, Senegal has achieved success through effective business management, value chain integration, capacity building and the enforcement of import suspensions since 2005 (Ba et al., 2022).

African countries with strong agricultural sectors and large domestic markets are highly attractive to foreign investors (Kubik, 2023; PARI, 2019f)**.** A well-performing, well-capitalized agricultural sector is a key driver of foreign direct investment (FDI) location decisions, especially for investors from higher-income countries. Additionally, a fast-growing domestic market with an emerging consumer class plays a crucial role, while public investments in agriculture and official development assistance can further stimulate FDI. For least-developed countries, market potential remains the most decisive factor for investors. To attract FDI in the food and beverage sectors, policymakers should prioritize agricultural sector development and create enabling conditions for investment.

India-Africa learning

The comparisons between Indian states and African countries with similar characteristics offer valuable insights into the policies that shaped their agricultural growth trajectories (PARI, 2021b, Figure 11)**.** Almost all Indian states and African countries have experienced substantial agricultural growth since 2000. Agricultural productivity has double in many areas while agricultural employment has declined, indicating ongoing structural transformation. While agricultural intensification drove India's output growth, many African countries relied on area expansion. Both regions benefited from agricultural diversification, which contributed to economic growth and nutrition improvements. Higher growth has been linked to improved nutrition and health. Despite these advances, India and Africa continue to face high levels of food insecurity.

Insights from well-performing African countries and Indian states underscore the critical role of integrated public investments in agriculture, education and social protection for economic growth and food security (PARI, 2024e)**.** However, in both regions, public investment in agriculture—particularly in agricultural research—remains insufficient. A significant portion of public funds is allocated to private goods like input subsidies and food aid, often leading to inefficiencies in the sector. Spending patterns reveal some differences: African countries tend to allocate more funds to research and knowledge dissemination than Indian states (though still inadequate), whereas Indian states direct twice the share of agricultural spending to infrastructure (24% compared to 13% in Africa). Regions with high agricultural growth rates demonstrate that prioritizing investments in producer support and infrastructure significantly boosts agricultural GDP and improves nutrition outcomes. Furthermore, countries that combine higher agricultural spending with investments in education and social protection achieve better overall performance in economic growth and child nutrition.

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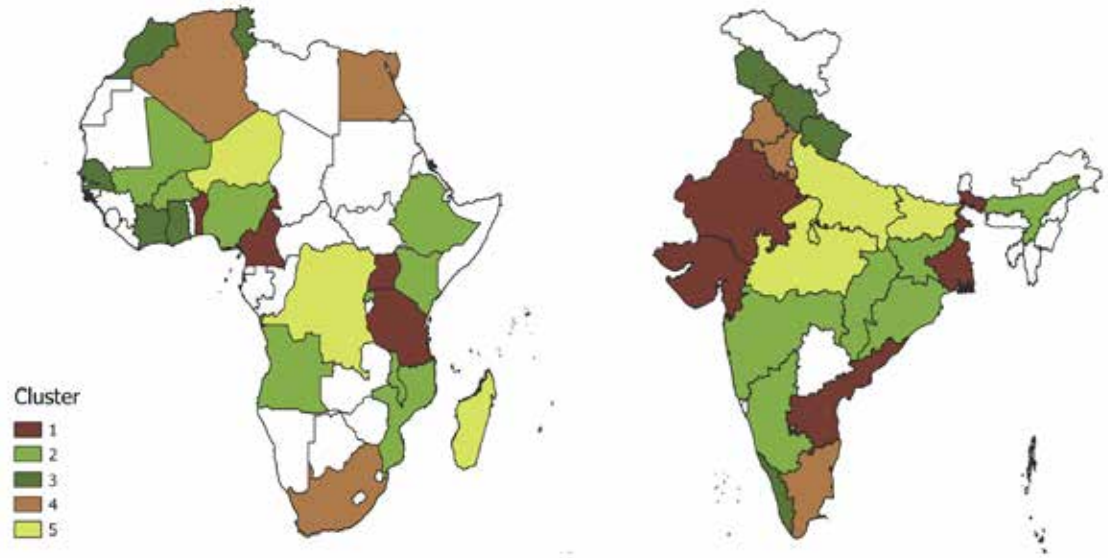
Figure 11: *Clusters of comparable African countries and Indian states*



Source: PARI (2021b)

2.12 COVID-19 POLICIES

KEY TAKEAWAYS

Food security and lockdowns: African countries prioritized food security during COVID-19, but lockdowns like workplace closures severely impacted nutrition and exposed gaps in social protection systems.

Agroprocessing resilience: Africa's agroprocessing sector rebounded despite raw material shortages and job losses, requiring better financial support, raw material access and worker safety nets.

India's Agri-Food Resilience: India's agriculture sector remained strong, but supply chain disruptions caused food inflation and affected perishable goods.

Migrant worker crisis: India's lockdown displaced millions of migrant workers, slashing incomes of return migrants by 85% and exposing weaknesses in relief measures for vulnerable populations.

During the first wave of COVID-19 in 2020, African countries faced a dilemma: strict lockdowns to curb the virus risked worsening food insecurity. Policy responses show governments often prioritized food security in their strategies (Birner et al., 2021). Contrary to the theory of policy diffusion—which posits that countries tend to emulate policies from higher-income nations—Benin, Ghana, Kenya, Uganda and Zambia developed lockdown measures tailored to their unique contexts. Their strategies reflected a careful balancing of food security concerns and political realities while responding to the high levels of uncertainty and urgency posed by the pandemic.

Despite these efforts, the food security impacts of lockdown measures could not be entirely avoided. Some measures, such as workplace closures and movement restrictions, were found to have far more severe effects on nutrition than others (Daum et al., 2022b)**.** By contrast, banning events and public gatherings had a comparatively minimal impact on food security. Prolonged lockdowns risk undermining households' resilience, resulting in dietary shifts, long-term health effects. They also pose challenges for social protection programs like food aid and cash transfers, which often struggled with governance issues and were unable to fully address the diverse impacts of lockdown measures on food access and nutrition. Understanding these nuances can help policymakers design nutrition-sensitive lockdown strategies to better safeguard food security during future pandemics.

The African agroprocessing sector showed resilience during the pandemic, with most firms in Ethiopia, Kenya, Nigeria, and South Africa beginning to recover within a year, albeit at reduced production levels (Baumüller et al., 2021; PARI, 2021c). The beverage sector was particularly hard-hit due to sales restrictions and many companies faced disruptions caused by foreign governments' measures, which hindered the import of inputs and the export of products. Despite these challenges, firms retained employees through strategies such as shift work or paid leave to manage production shortfalls. However, some impacts worsened over time. By October 2020, access to raw materials—already a concern earlier in the year—had deteriorated further, forcing more firms to lay off workers or reduce salaries. To support firms and their employees, policymakers should prioritize financial assistance for companies, improved access to raw materials and the establishment of social safety nets for workers.

India's agri-food system also demonstrated a fairly high level of resilience during the pandemic, though the impacts varied by sector and were marked by disruptions in supply chains that drove food inflation (Gulati et al., 2021). Labour shortages, rising transportation costs and intermittent closures of wholesale mandis disrupted the efficiency of agri-food supply chains. Despite these challenges, the agricultural sector and parts of the food processing industry—particularly grain milling, dairy and oil production—performed well. However, the processing and preservation of meat, fruits and vegetables were adversely affected. Supply chain disruptions also caused food price hikes, with the consumer price index rising by 2.9% in March 2020 and further escalating in the following month. Price increases were particularly pronounced for pulses, oils and perishables such as onions and tomatoes, reflecting the strain on supply chains.

One of the most devastating crises to emerge in India during the pandemic was the unprecedented migrant worker exodus (Gulati et al., 2021; PARI, 2021d). The sudden imposition of a nationwide lockdown in March 2020 forced millions of migrants to return to their home villages. With limited employment opportunities in rural areas, household incomes among migrants fell by 85% between June and August 2020. A third of these workers were unable to return to their workplaces even after the lockdown was lifted, while those who did experienced an 8% decline in income compared to pre-lockdown levels. The central government introduced various relief packages to support vulnerable populations, but most failed to adequately reach migrant workers. Consequently, many migrants reported a decline in the quality of food consumed during and after the lockdown. These gaps highlight the urgent need to revise social safety measures to better address the needs of vulnerable populations during future shocks.

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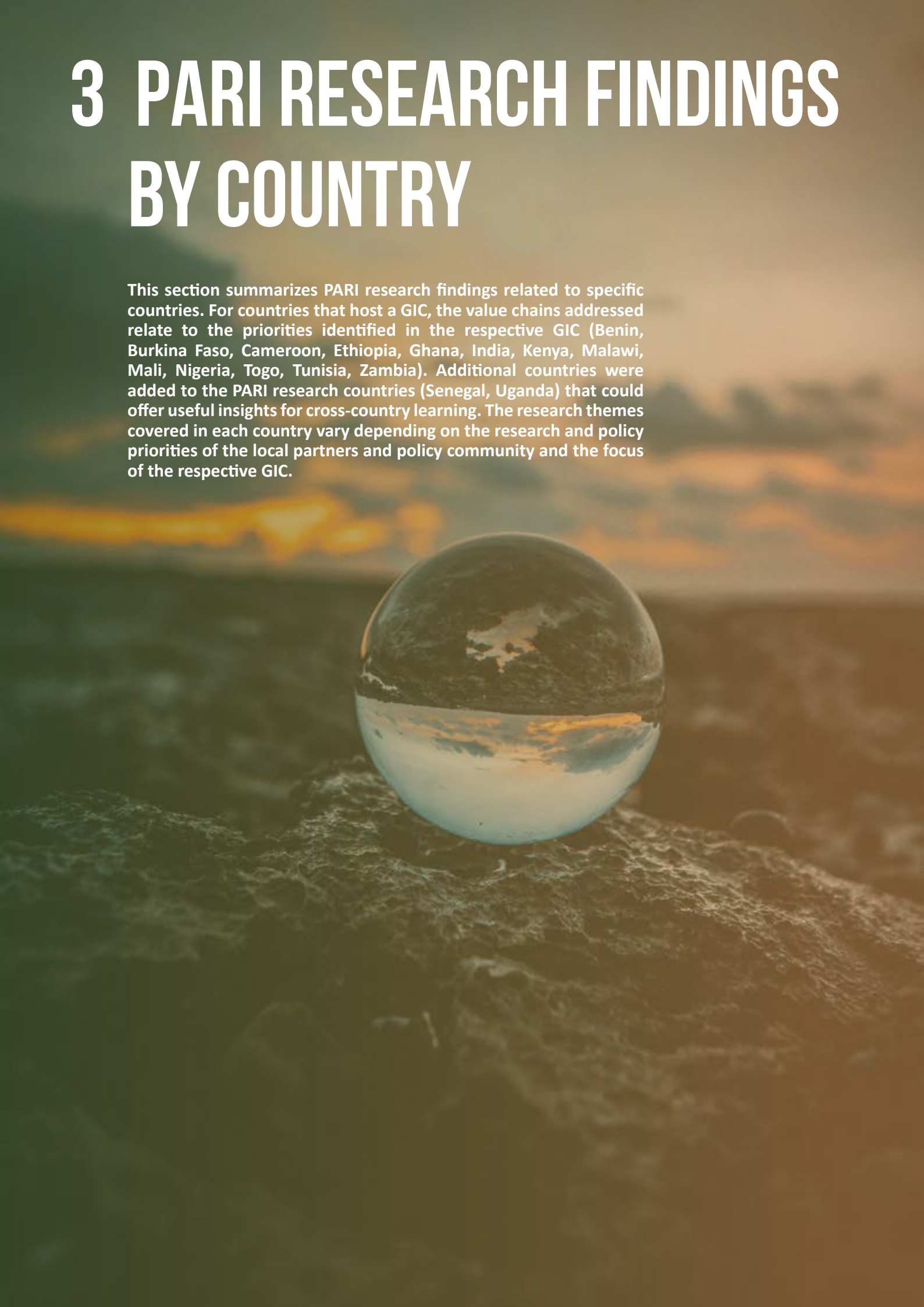
3 PARI RESEARCH FINDINGS BY COUNTRY

This section summarizes PARI research findings related to specific countries. For countries that host a GIC, the value chains addressed relate to the priorities identified in the respective GIC (Benin, Burkina Faso, Cameroon, Ethiopia, Ghana, India, Kenya, Malawi, Mali, Nigeria, Togo, Tunisia, Zambia). Additional countries were added to the PARI research countries (Senegal, Uganda) that could offer useful insights for cross-country learning. The research themes covered in each country vary depending on the research and policy priorities of the local partners and policy community and the focus of the respective GIC.



3.1 BENIN

KEY TAKEAWAYS

Input and technology access: Limited access to improved seeds, fertilizers, veterinary services and machinery constrains productivity in Benin. Expanding access is crucial for growth.

Impactful innovations: Innovations in crops and livestock have boosted productivity and incomes in the country but face low adoption due to limited awareness and scalability.

Mechanization challenges: Mechanization enhances productivity and employment but is hindered by high costs, limited skills and dependence on imports. Supporting local manufacturing and services is key.

Youth in agriculture: Agriculture offers significant employment potential for youth, especially in agro-processing, but requires better investment, training and awareness to realize its potential.

Climate adaptation: Climate-smart practices like short-cycle crops and mulching improve resilience. Scaling these methods and exploring carbon credits could further support Benin's farmers.

Selected value chains

The rice, soybean and poultry value chains were initially selected for Benin's GIC due to their significance in the country. **Rice** is a staple cereal critical to food security in Benin, with annual per capita consumption of milled rice averaging 15–20 kg. It serves as an essential source of calories (INRAB et al., 2017). However, the majority of rice consumed in Benin is imported—primarily from Asia—rather than locally produced.

Soybean production has been growing rapidly, , increasing 10-fold from around 50'000 tonnes in 2000 to 525'00 tonnes in 2022 (FAO, 2024b). This growth is driven by supportive government policies, consumption growth and mills gradually replacing cotton seeds with soybean.

Poultry farming is traditionally practiced by the large majority of Benin's rural population. Women play a vital role in both the production and commercialization of poultry (Adegbola et al., 2016; Mbaye et al., 2018).

Innovations in value chains

Lack of access to improved seeds is a significant constraint for soybean and rice production in Benin. Similarly, poultry and small ruminant farming face challenges due to limited veterinary services and rudimentary infrastructure (Adegbola et al., 2018a; INRAB et al., 2017; Mensah et al., 2017). The average quality of rice produced in Benin is low, with 30–35% often consisting of broken grains. Soybean yields remain low at around 1.1 tonnes/hectare in 2022, less than half that of the global average of 2.6 tonnes/ha. Rural storage conditions make it difficult to preserve the germination properties of soybean seeds intended for replanting. Farmers also have limited access to fertilizers, pesticides (except for cotton), machinery, credit and modern technology. Additionally, the absence of regulations for water management and the lack of improved water infrastructure in rice valleys negatively affect rice yields and, consequently, farmer incomes. Other challenges include disagreements within farmer associations, lack of trust and unequal access to resources. In small ruminant farming, key constraints are the high prevalence of diseases (e.g., mange and diarrhea), degradation of fodder and shrinking pasture space caused by continuous land reduction.

To address these challenges, Benin has developed innovations across plant, animal and fish production systems. These advancements focus on technical improvements, new equipment, better access to inputs, improved seeds and breeds and knowledge transfer (Adegbola et al., 2016; Mensah et al., 2017). These innovations have positively impacted yields, farmer incomes and resilience to climate change. Some examples of specific value-chain innovations include:

- **Rice:** improved seeds, rice threshers, rice grading machines, rice milling machines for rice;
- **Soy:** dried soy flour, soy cheese production, soy yoghurt production;
- **Pineapple:** production of pineapple jam, jelly, powder and pineapple-based alcohol, wine, vinegar;
- **Cashew:** improved cashew nut peelers, powered cashew nut grinders, cashew fruit harvesting nets, cashew juice with gelatine and cashew nut flour of dried cashew; and
- **Small ruminants:** improved feeding techniques based on harvest by-products and agro-food processing by products, sharecropping agreements for improved breeds of sheep and goats

Farmers in Benin generally perceive agricultural technology innovations as beneficial, citing increased yields and income, time savings and— to some extent— improved food security (Adegbola et al., 2018b). For instance, in soybean production, farmers highlight the advantages of improved varieties, such as shorter cultivation periods (90–100 days), adaptability to local climates, appealing appearance and higher yields. Similarly, in rice production, farmers consider cultivating improved rice varieties the most profitable innovation compared to other technologies (e.g., improved steaming kits). These varieties are valued for their high yields, drought resistance and adaptability to local climates. Innovations in rice processing, such as steaming kits and threshing machines, are praised for saving time and labour, increasing women's incomes and reducing food losses. In the small ruminant and poultry sectors, several innovations have been well-received by farmers. For example, an under-basket breeding system has reduced

chick mortality from 79% to 56%, while providing a suitable habitat for small ruminants in flooded areas has decreased mortality to 0%. However, these technologies remain underutilized due to low awareness.

The engagement and commitment of stakeholders—primarily research institutions, extension services and funding bodies—and the alignment of innovations with the aspirations of end user, are critical to the success of agricultural innovations in Benin (Kouévi and Fatunbi, 2019). One notable success is the NERICA-L14 rice variety, developed by Benin's National Agricultural Research Institute (INRAB). This variety is pest-resistant and delivers high yields, making it a widely adopted innovation now cultivated throughout the country. Another successful innovation is the clean BENTO 01 tomato variety, which provides growers with access to high-quality, disease-free tomato seeds. This initiative was funded by the government and the Mono and Couffo Rural Development Support Project (PADMOC), with research support from the Territorial Agency for Agricultural Development (ATDA) and INRAB. Today, demand for this variety is high, with 90% of vegetable growers using it. In cashew nut processing, a manual sheller has significantly improved efficiency by reducing the rate of broken nuts and enhancing export quality. This sheller allows an individual to process up to 100 kg of cashew nuts per day. Its success stems from collaboration between researchers and manufacturers. However, some technologies have failed to gain traction among farmers due to insufficient testing, lack of refinement, or poor commercialization (e.g. the rice-based Pella breakfast and techniques for Amaranthus seed production).

Mechanization

Farmers in Benin prioritize price and horsepower when buying tractors. Maintenance and access to spare parts remain key challenges for mechanized agriculture (Adegbola et al., 2020b). A survey revealed that all tractors in Benin are imported, with Mahindra and Massey Ferguson being the most preferred brands due to their quality, durability and availability of spare parts and repair technicians. Tractors are mainly used for plowing and transportation. Few operators benefit from after-sales services; maintenance is typically done at workshops, while repairs are handled by independent technicians, owners, or assistants. Tractor breakdowns are often caused by the lack of spare parts and repair expertise. Building technical skills among stakeholders—such as producers, technicians and drivers—is crucial to improve tractor durability and reduce breakdowns. Collaborating with international companies to support local assembly and fabrication could further boost mechanization and reduce dependency on imports.

Tractors have increased incomes, productivity and employment among smallholder farmers in Benin (Adegbola et al., 2020b). Farmers report community-level benefits such as reduced disease, increased wealth, more schooling, higher birth rates and lower death rates. At the household level, mechanization boosts income, food security and access to credit while providing farmers more free time, which they use for other activities, rest, or family engagement, strengthening cohesion and improving women's roles in decision-making. However, mechanization also deepens gender inequalities, as women often lack access to tractors due to social norms and smaller farm sizes (Daum et al., 2020b). Environmentally, it reduces slash-and-burn practices but increases soil compaction, flooding, erosion and deforestation due to expanded cultivation.

Mechanized farming is becoming an attractive employment option for young people in Benin, with tractor driving being a particularly desirable profession. However, limited tractor use across the country restricts opportunities (Adegbola et al., 2020b; Daum et al., 2020b). Specialized programs at public and private institutions, including agricultural schools and universities, provide training in mechanization practices. Short-term courses offer young people practical skills, such as equipment use and maintenance, tractor driving, hitching accessories and manufacturing. Strengthening training centers is essential and requires better materials, upgraded facilities, research funding, promotional events and improved contracts for teaching staff.

The production of agricultural machinery presents lucrative opportunities for local manufacturers, but support measures are needed to grow the sector. These include improved access to finance, skill development and quality assurance (Adegbola et al., 2022; Daum et al., 2023a). A survey of local manufacturers indicates gradual expansion, particularly in the post-harvest segment. Commonly produced machines include seed drillers, mills and shelling machines, while the highest profits come from power tillers, thresher-cleaners, dryers, huskers and harrows. Larger machinery, however, is mostly imported. Manufacturers also generate income through after-sales services, offering spare parts, warranties and emergency repairs. The growing machinery rental market could further expand business opportunities. To support the sector, key measures include better credit access for raw materials and tools, investments in technical training, research to drive innovation, quality standards to ensure durability and contract enforcement mechanisms. The *Stratégie Nationale de Mécanisation Agricole* (SNMA) (2022–2026) provides a significant opportunity to address challenges like limited skills, financial constraints and high costs of electricity and raw materials, creating an enabling environment to boost local machinery production.

Skill development

The government of Benin is investing in expanding ATVET. While students are generally satisfied with the quality of training, further investment is needed in practical training, digital skills, school facilities and greater engagement of women (Adegbola and Zossou, 2024). The ATVET system includes public and private universities, agricultural technical colleges and professional training centers. By 2025, the government plans to establish 25 vocational schools dedicated to agricultural education. A survey of students in ATVET programs shows that 49% aspire to become agripreneurs and 23% aim to work in extension services. Most students are satisfied with course content, finding it relevant and taught by qualified, approachable teachers. However, they identified gaps in digital skills training, practical work opportunities and access to internet, computers and literature. Women remain underrepresented, making up only a third of

students and 12% of teachers. Addressing these gaps will require increased public investment and better alignment of development assistance with national priorities.

Employment

Benin has implemented national initiatives to create job opportunities for youth, but funding for employing recent graduates remains a key barrier. Entrepreneurship offers a promising alternative (Adegbola et al., 2020a). Government programs targeting services, wage subsidies, public works and self-employment have reached many young people but face institutional challenges that limit their impact. Improvements are needed in monitoring beneficiaries, providing training and finance and raising awareness about these programs. Public-private partnerships should also be encouraged to offer practical training and internships in areas like food processing, financial management, marketing and innovation, while shifting attitudes from salaried jobs to entrepreneurship (Adegbola et al., 2022).

In rural areas, agriculture has significant potential to employ youth, especially in processing, but remains underutilized due to low investment, lack of information and the physical demands of agricultural work (Adegbola et al., 2020b). The Agricultural Entrepreneurship Promotion Project (PPEA), for instance has helped young people gain farm skills, increase self-employment and create more community-level jobs. However, the sector's full potential remains unrealized. Policies should promote awareness of agricultural opportunities, offer agro-processing training and increase financing for agribusiness ventures. Short-term agriculture-related courses, apprenticeships and internships are critical for engaging youth in agribusiness and unlocking the sector's potential.

Climate change adaptation and sustainability

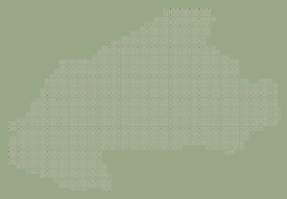
Adaptation strategies can help Beninese farmers cope with climate change and boost their incomes (Adegbola et al., 2017a). Farmers in Benin are increasingly affected by rainfall variability and droughts, which disrupt agricultural production. In response, many rely on cultural practices, such as rainmaking and sacrifices and have adopted short-cycle rice and maize varieties along with mulching techniques using plant residues. While these short-cycle varieties help mitigate financial losses, they provide only modest revenue increases. To further support farmers, more climate-smart practices should be promoted. Such practices not only enhance resilience but can also reduce greenhouse gas emissions, particularly in rice fields. Exploring opportunities for farmers to earn carbon credits for emissions reductions could provide additional financial benefits.

Nutrition

Personalized nutrition advice could be a valuable tool to address malnutrition, but significant challenges remain in achieving more comprehensive changes in dietary patterns (Behrendt et al., 2024). Field-testing a digital food recommender in Benin showed positive effects on reducing carbohydrate intake but no significant changes in other micro- or macro-nutrients, highlighting the challenges of achieving a balanced diet. Developed by the Technical University of Munich, the recommender system uses household eating behavior data to provide tailored advice, suggesting adjustments to up to three food items to combat malnutrition and obesity. While recommendations to reduce carbohydrate consumption were effective, suggested changes for increasing specific vitamins had limited impact, likely due to the unavailability of certain foods and the greater complexity of balancing micronutrients compared to carbohydrates.

PARI Annual Research & Planning meeting 2018 in Benin, 2018

3.2 BURKINA FASO



KEY TAKEAWAYS

Challenges in value chains: Rice and sesame production face high costs, low yields and unstructured markets in Burkina Faso, with rice struggling against subsidized imports.

Climate-resilient innovations: Practices like Zaï Pits and weather index insurance improve yields and climate adaptation but need broader assessment and support.

Mechanization gaps: High costs, small farms and lack of spare parts hinder mechanization, with most farmers relying on animal power and manual labour.

Irrigation needs: Drip irrigation and rainwater harvesting can boost productivity but require more funding, research and complementary strategies.

Selected value chains

The rice and sesame value chains were initially selected for the Burkina Faso's GIC (INERA et al., 2017). **Rice** production is central to Burkina Faso's national food security strategy, which focuses on intensifying local production, improving quality and enhancing market access. Currently, about half of the country's rice demand is met through imports of low-quality rice. Notably, there are no commercial rice producers or millers in the country.

Sesame, by contrast, is an export-oriented crop. It is attractive to farmers due to its higher profitability per hectare compared to cotton, lower labour requirements, drought tolerance and the convenience of cash payments at the farm gate. However, local demand for sesame is minimal, with most production exported to Asia and Europe, especially for organic markets.

Innovations in value chains

Barriers related to productivity, institutions and trade are the main constraints to expanding rice and sesame production in Burkina Faso (INERA et al., 2017). Rice producers face high production costs, stagnant rice prices, low investment in the sector and a lack of equipment. Additionally, they compete with subsidized imported rice, which dominates the market. In the sesame value chain, yields are impacted by climate change, while commercialization is hindered by institutional challenges such as unstructured markets, contract violations and limited access to credit (ZEF, FARA, and INERA, 2017). Both value chains also face significant challenges in processing due to inadequate capacity and infrastructure.

Agricultural innovations in Burkina Faso have improved yields through better soil management, seed quality and market access (INERA et al., 2017). To restore soil fertility and rehabilitate dry lands, farmers have adopted the Zaï Pit technique, which collects and retains water to reduce water stress in areas with low or erratic rainfall. This low-cost method is easy to implement and evidence from Niger shows it can double yields. Another climate-related innovation is weather index drought insurance, which has been linked to increased yields and savings. In the cotton sector, the introduction of genetically modified Bacillus thuringiensis (Bt) cotton boosted production by up to 57.5%. While this variety increased profits through higher yields, its poor quality led to lower international prices, prompting Burkina Faso to discontinue Bt cotton in 2016. Other innovations include contract farming, farmer unions and counters to improve market visibility, information exchange and bargaining power among cotton farmers. While these approaches are well-received, their impacts remain unassessed.

The involvement of multiple stakeholders is essential for the adoption and dissemination of agricultural innovations in Burkina Faso (INERA et al., 2017). A prime example is the scaling-up of the System of Rice Intensification (SRI). Starting as a small trial in 2006, SRI is now widely adopted among rice producers with support from local and international organizations (e.g., FAO, World Bank, CODEGAZ, USAID), the government and research institutes. SRI has the potential to double average rice yields. Similarly, a multi-stakeholder project to improve sesame yields focused on soil fertility, better seeds and farmer training. Modest fertilizer use increased yields by 75%, while improved seeds more than tripled initial investments. Farmer schools proved effective in teaching seed breeding and fertilizer application. In the milk value chain, a multi-stakeholder platform helped establish collection systems to supply mini-dairies. Although milk production remains suboptimal due to low quality and lack of fodder, the platform has the potential to address these issues. Proposed solutions include providing feed concentrates, training producers to grow high-nutrition forage and teaching farmers to preserve and convert crop residues into feed (Ouédraogo et al., 2019a).

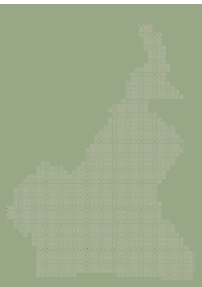
Mechanization

High costs, small farm sizes and limited access to spare parts and repair services hinder the adoption of mechanized agriculture in Burkina Faso (Ouédraogo et al., 2019b). Despite government interest in modernizing agriculture, mechanization rates remain low. In the Béréba and Koumbia regions, farmers primarily use tractors for ginning, threshing, transportation and ploughing due to their efficiency. However, the high cost of renting tractors forces many to rely on animal draught power, especially for ploughing, while other tasks like weeding, sowing and harvesting are done manually or with animal power. Low demand for mechanized services is also driven by field conditions that limit tractor efficiency. Additionally, the unavailability of spare parts is a major issue. Mechanics often modify incompatible parts from other brands, shortening tractor lifespans, or travel to Ghana to source parts, causing lengthy delays. Investments in specialized training and better access to spare parts could help increase demand for mechanized services and improve adoption rates.

Climate change adaptation

Irrigation innovations are essential for boosting Burkina Faso's agricultural productivity and climate change adaptation (Sylla et al., 2021). Key technologies include drip irrigation, which reduces water and fertilizer use and rainwater harvesting, which mitigates water stress through systems like impluviums, ponds, sand dams and underground tanks. These technologies are especially vital for drought-affected crops like sorghum, a major staple for 80% of Burkina Faso's rural population. Even a 1mm increase in rainfall could raise cereal yields by 385 tonnes in the long term and 252 tonnes in the short term (Igue and Sossou, 2021). However, these innovations remain in their early stages and require more research and funding to reach their potential. Complementary strategies, such as improved seeds, smart agriculture practices and large-scale irrigation infrastructure, are also needed to reduce vulnerability to climate shocks.

3.3 CAMEROON



KEY TAKEAWAYS

Agricultural constraints: Cameroon faces low productivity due to poor access to inputs, credit, mechanization and storage, with specific challenges in poultry, cacao and potato value chains.

Innovations and opportunities: Innovations like pest-resistant seeds and farmer training have improved productivity, while rising urban demand for potatoes offers growth potential if consumer needs and production are enhanced.

Selected value chains

The potato, cacao and poultry value chains were initially selected for Cameroon's GIC due to their economic and social importance (IRAD et al., 2017). **Potato** is a key cash crop that supports food security and poverty alleviation, with women as primary cultivators and youth heavily involved in processing (Noe et al., 2019; Okolle, 2019). Urban demand for Irish potatoes is rising due to consumer preferences for their taste.

Cacao, Cameroon's most valuable agricultural export, accounts for 4% of global cocoa production and serves as the main income source for forest communities. However, institutional barriers, such as low prices offered by intermediaries, limit the sector's competitiveness.

Poultry contributes about 9% of the animal protein consumed in Cameroon and generates approximately USD 30 million annually. The domestic sector benefits from import restrictions, with growing urban demand for traditionally raised village chicken due to its preferred taste over commercial chicken.

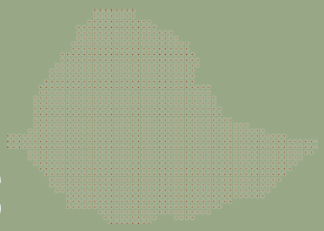
Innovations in value chains

Cameroon's agricultural productivity is constrained by limited access to inputs and credit, low investment in research, low mechanization adoption and inadequate storage and processing facilities (IRAD et al., 2017; Okolle, 2019). Specific value chains face additional challenges. In chicken farming, growth is hindered by poor sanitary conditions, low-quality feed, lack of capacity building and competition from imported frozen chicken. In cacao production, low productivity stems from aging farmers, old plantations and limited access to inputs and services. For potatoes, major issues include rot outbreaks and insufficient storage, as warm, humid conditions make preservation difficult despite year-round harvesting.

Agricultural innovations in Cameroon have promoted best practices in pest management, crop production and post-harvest processes across various value chains (IRAD et al., 2017; Okolle, 2019). For beans, proper drying before storage has been emphasized to prevent molding. In the cocoa sector, efforts focus on biodiversity conservation and diversifying farmer incomes through agroforestry landscapes (CALs) and non-timber forest products. Small-scale cassava producers, primarily women, have benefited from disease-free planting materials and training in processing and marketing. Similarly, sorghum and maize producers have received improved seeds, inputs and extension services through Diageo's initiative to ensure a stable supply for beer production. Farmers of traditional African vegetables, such as amaranth, African nightshade, jute mallow and African eggplant, have been given pest- and disease-resistant seeds along with training in cultivation practices. Banana producers also received a pest-resistant plantain hybrid. All these innovations were supported by various international and local agencies.

Rising urban demand for potatoes in Cameroon offers significant market opportunities for the potato value chain. Understanding consumer preferences for varieties and processing methods is key to leveraging this demand (Noe et al., 2019). A marketing study shows that specific varieties are suited for different purposes: Cipira and Mumbi are ideal for fries, while Banso and Belo are preferred for chips, mashing and roasting. Urban consumers, especially young people, increasingly favor fries, driven by the trend of eating outside the home. Marketing is primarily led by hotels and restaurants, with small food stalls lacking a clear strategy. To strengthen the value chain, efforts should focus on promoting the nutritional benefits and versatility of potatoes while supporting farmers to boost production.

3.4 ETHIOPIA



KEY TAKEAWAYS

Agricultural challenges: Ethiopia's productivity is constrained by rainfall variability, land tenure insecurity, limited input access, weak extension services and poor infrastructure. Low adoption of fertilizers and improved seeds persists, despite their potential to boost yields.

Farmer innovation: Ethiopian farmers create cost-effective, locally adapted solutions, but these need better validation, commercialization and targeted support for women innovators.

Mechanization in processing: Continuous training is needed to assist companies and workers in the adoption of machinery in processing.

Youth in agriculture: Young agripreneurs face barriers like limited credit and land. Training and funding programs are crucial for their success.

Women's burden: Women's time poverty from unpaid domestic work requires solutions like better infrastructure, electricity and agricultural technologies.

Market access for nutrition: Market integration impacts dietary diversity more than production diversity. Policies should enhance market access and food variety for rural households.

Selected value chains

The wheat, faba bean and honey supply chains were initially selected for Ethiopia's GIC (Bahir Dar University et al., 2017). Despite steady growth in **wheat** production, wheat remains Ethiopia's top import.

In contrast, Ethiopia is the largest producer of **faba beans** in Africa and the second largest globally, with faba beans accounting for 36% of the country's pulse production. They are a key source of protein and nutrients for smallholder farmers and offer higher net returns compared to other pulses, such as chickpeas (Goshu et al., 2019).

Ethiopia also leads Africa in **honey** production and ranks tenth globally. However, less than 2% of honey is exported. The country aims to triple average honey yields from 10kg to 30kg per hive to boost production (Tegegne and Legese Feye, 2020).

Innovations in value chains

Agricultural productivity in Ethiopia faces numerous challenges, including climate factors (e.g., rainfall variability, droughts), institutional barriers (e.g., land tenure insecurity) and limited access to inputs, information and credit (Bahir Dar University et al., 2017). State ownership of land restricts farmers' land rights, reducing efficiency and investment. Low adoption of fertilizers, improved seeds and pesticides, combined with weak research and extension services and inadequate storage and transport infrastructure, further hinders productivity. In the livestock sector, droughts and floods are key constraints, exacerbated by weak institutional arrangements and limited access to technology. Similarly, Ethiopia's honey sector, despite its potential, is underutilized, with low adoption of modern production technologies (Tegegne and Legese Feye, 2020).

Rainfall variability and crop diseases significantly impact wheat and faba bean production in Ethiopia, yet adoption of drought- and pest-resistant seeds and fertilizers remains very low (Feiruz et al., 2019; Goshu et al., 2019). Only a small share of producers use chemical fertilizers and improved seeds, despite their potential to boost yields. Farmers are more likely to adopt fertilizers than improved seeds, with larger farmers being more inclined to use improved seeds. This is partly due to the limited availability of high-yielding, disease-resistant cultivars. To improve productivity, better access to inputs, greater farmer awareness and research on high-yielding, disease-resistant and climate-adapted crop varieties are urgently needed.

Digitally enabled innovations, such as information and insurance services, have supported Ethiopian farmers in improving productivity (Bahir Dar University et al., 2017; Tegegne and Legese Feye, 2020). A popular agricultural hotline launched in 2014 provides farmers with advice on cultivation practices. Additionally, since 2008, the Nyala Insurance Company has offered two types of crop insurance for rain-fed and drought-prone areas. In the livestock sector, index-based insurance protects pastoralists against forage scarcity using remotely sensed vegetation indices. When forage availability falls below a threshold, pastoralists receive compensation to buy inputs and avoid selling assets. To further boost technology adoption and information dissemination, providing on-farm extension services and encouraging community gatherings is essential (Ahmed and Getahun, 2019).

Ethiopian livestock farmers have benefited from improved management practices and greater access to inputs (Tegegne and Legese Feye, 2020). Key innovations include advancements in feed production and marketing, as well as the adoption of integrated feedlot operations. To combat soil erosion, efforts have focused on soil management techniques, such as planting legumes as ground cover and implementing water harvesting systems. Additionally, the rehabilitation of degraded lands and the cultivation of diverse perennial crops, such as coffee and fruit trees, hold significant potential to boost honey productivity.

In Ethiopia's honey sector, improved access to extension services can increase productivity by enhancing the supply of high-quality frame hives and provide entrepreneurial training (Tegegne and Legese Feye, 2020). Despite being one of Ethiopia's driest regions, Tigray leads in honey production due to strong regional government support for extension services, improving technical skills and knowledge in beekeeping. The Young Entrepreneurs in Silk and Honey project has also boosted apiary centers and modern hive adoption in the region. Beekeeping is a traditional livelihood for 1.7 million rural households, playing a cultural and religious role while

offering opportunities for youth employment. However, the sector remains supplementary to other agricultural activities, with low adoption of modern technologies. Regular technical supervision, improved financing and investments in apiculture could increase adoption rates and deliver ecosystem benefits like enhanced pollination.

Farmer innovations

Ethiopian farmers can be a valuable source of locally adapted innovations. Support is needed to validate these innovations, assist entrepreneurs in commercialization and empower women innovators (Tambo, 2018). A review of submissions to a farmer innovation contest organized by PARI shows that two thirds of participating farmers developed original innovations, while the rest adapted existing technologies to better suit local conditions. Motivated by curiosity and cost reduction, the majority focused on technical innovations, particularly in livestock production (34%), farm tools (26%) and crop management (13%). These innovations were typically low-cost (USD 20 or less) and used locally available materials, making them highly cost-effective. Farmers reported that their innovations increased knowledge, improved yields and reduced labour demands. While about 60% were aware of others adopting their innovations, more support is needed to validate and commercialize promising ideas. Women were underrepresented, contributing only 10% of innovations, highlighting the need for targeted efforts to encourage and showcase women innovators.

Employment

Young Ethiopian entrepreneurs are increasingly engaging in the food and agricultural sector, which can be more financially rewarding than other industries, but they are constrained by limited access to finance, land shortages and poor raw material supply (Nigus et al., 2022). A survey of 199 young agri-entrepreneurs in Amhara, Oromia and Sidama states revealed that youth focus primarily on livestock and crop production, food processing and, to a lesser extent, food retail. There is no significant difference in high school completion rates between those in agribusiness and those who are not. However, successful agripreneurs often have formal education, training, or farm work experience, as well as access to wealth, assets, family connections and social networks. Many agribusinesses are start-ups rather than inherited ventures, often supported by NGOs, international organizations, or government programs. For example, beneficiaries of the "Youth Revolving Fund" have successfully launched businesses using these funds (Getahun and Fetene, 2020b). To enhance youth success in agribusiness, it is crucial to provide training in accounting and recordkeeping, facilitate bank account setup, reduce bureaucratic barriers and increase funding for start-ups.

Ethiopia has implemented several national policies to increase employment opportunities for young people, particularly in rural areas. While unemployment rates have declined, the impact of these initiatives is difficult to assess due to a lack of data (Getahun and Fetene, 2020b). Since 2000, at least four major policy interventions have targeted youth unemployment, providing funds, land, market information and training. For example, the National Rural Youth Development Package (2006) allocated land for agroforestry to young people. However, limited data on job creation, fund utilization and implementation challenges have hindered the evaluation and monitoring of these programs. Additionally, many policies lack clear objectives and measurable targets. For instance, the National Youth Policy (2004) does not specify actionable goals, making it difficult to assess its outcomes. Establishing robust monitoring and follow-up mechanisms would improve outreach and enable better evaluation of program effectiveness. Addressing these gaps would help refine future policies to further reduce youth unemployment.

Attracting young Ethiopians to agriculture and expanding off-farm activities in rural areas could help reduce out-migration. A study on rural youth employment aspirations found that most young people prefer non-agricultural jobs and aspire to high socio-economic status occupations (Mussa, 2020). Youth interested in further schooling are less likely to migrate, though evidence on their aspirations in agriculture is limited. Policies should align youth aspirations with rural opportunities to make farming more appealing. Key measures include improving access to technology, developing rural infrastructure and supporting the growth of non-farm sectors.

Ethiopia's agro-processing sector creates jobs, particularly for skilled women and youth, but greater investment in raw materials and infrastructure is needed (Getahun and Fetene, 2020a). Food production industries generate more jobs than beverage industries, though the sector overall offers fewer jobs per unit of capital compared to chemicals and metals. Most food and beverage manufacturers are small (43%), with medium and large enterprises comprising 27% and 31%, respectively (Baumüller et al., 2023b). These firms are predominantly privately and domestically owned, with half focused on grain milling and others spanning diverse sub-sectors. Key challenges include unreliable electricity, reliance on imported inputs and limited access to foreign currency. To unlock the sector's potential for economic growth and job creation, efforts should focus on substituting imported inputs with local raw materials and improving electricity infrastructure to reduce blackouts and ensure reliable power supply.

Mechanization and automation in Ethiopia's agroprocessing sector have not yet caused significant job losses, but targeted training programs are needed to close technical skill gaps and help employees adapt to new technologies (Baumüller et al., 2023b). A survey of manufacturers shows that all firms use machinery for processing and packaging, with 20% employing computer-controlled automation. Most machines are imported from Asia and Europe. Reported benefits include improved product quality, greater efficiency, reduced costs and lower food waste. While 96% of firms believe their staff are qualified to operate these systems, gaps in technical and computer skills remain. Automation has not led to widespread layoffs—only 9% of firms reduced staff after their last major investment, while 27% reported job gains. Many workers in automated firms have been reassigned to new tasks as needed. To help employees adjust to advancing technologies, technical training programs are essential. Additionally, social safety nets should be implemented to address potential job losses in the future.

Climate change adaptation

Efforts at the local and national levels have helped to address impacts of land degradation and climate change in Ethiopia, but significant challenges persist (Admassie and Abebaw, 2021). Land degradation is a critical issue, particularly in the mountainous highlands, where rainfall variability and droughts undermine agricultural productivity. Farmers traditionally diversify crops and livelihoods to cope with agricultural shocks, but adoption of climate-smart technologies—such as agroforestry, rainwater harvesting and drought-tolerant crops—remains low. The government has introduced programs like the Agricultural Growth Program, Productive Safety Nets Program, Sustainable Land Management Program and Climate Resilient Green Economy Strategy to support agriculture. Despite these efforts, agriculture remains heavily rain-fed and invasive species are spreading, particularly in the lowlands where much of the livestock production occurs.

Women empowerment

Women in Ethiopia continue to bear the majority of unpaid work. Investments in services and infrastructure, such as electricity, markets, roads and agricultural technologies, could help reduce their time burdens (Getahun and Mekonnen, 2024). On average, women work 10 hours per day compared to 8.6 hours for men, with the gap more pronounced in large, low-income and less-educated households where women face greater time poverty. Household labour is highly gendered, with unpaid tasks largely falling to women and children, while men focus on paid work. As a result, women's dual role in paid and unpaid work leaves them with just 0.73 hours of leisure per day, compared to 1.48 hours for men. Improving access to electricity and agricultural technologies can help reduce women's unpaid workloads and increase leisure time for all household members.

Nutrition

Market integration in Ethiopia has a greater impact on household dietary diversity than production diversity alone (Getahun and Fetene, 2021). A study of panel data from 7,110 rural households found that improved market access positively affects both household and individual diets. Many households focus on cultivating high-value crops to boost income and access a wider range of foods through markets. Risk-averse farmers, larger farm owners and those participating in community meetings are more likely to diversify crops. Cereal production and livestock farming dominate, while dairy, fruits and vegetables remain less common. Similarly, starchy foods, vegetables and pulses are widely consumed, whereas fruits, meat and eggs are less prevalent. This indicates that policies focused solely on production diversity may not significantly improve nutrition. Instead, these efforts should be paired with strategies to enhance market access, particularly for poorer households. Supporting the adoption of agricultural technologies can further boost productivity and contribute to better nutrition and food security. More research is needed on how production diversity impacts the nutrition of children and lactating women.

3.5 GHANA

KEY TAKEAWAYS

Agricultural innovations: Improved seed varieties and partnerships have boosted productivity in Ghana, but better input access and extension services are needed to scale successes while addressing failures.

Farmer innovations: Farmers' locally adapted solutions boost resilience and income but require stronger support systems, including knowledge-sharing, access to modern tools and collaboration with stakeholders.

Digital agriculture: Ghana's digital agricultural services support extension, marketing and finance but need investments in digital literacy, lower internet costs and advanced technologies like drones to scale effectively.

Employment in agroprocessing: Agroprocessing outpaces farming in job growth. Investments in training, mechanization and infrastructure are crucial to enhance product quality and support local rice competitiveness.

Women empowerment: Heavy unpaid work limits women's economic participation. Time-saving technologies, childcare, water infrastructure and gender equality initiatives can empower women and benefit households.

Selected value chains

The maize and rice value chains were initially selected for Ghana's GIC initiative (CSIR et al., 2017). These two crops are Ghana's leading cereals and collectively account for approximately 80% of the country's total grain production. **Maize** is predominantly cultivated to meet local demand, with 57% consumed by farming households, 30% traded through both formal and informal markets and 13% used as poultry feed.

To reduce reliance on imports, the government has prioritized increasing rice production through the National Rice Development Strategy (NRDS). Despite this effort, imported rice remains the preferred choice for many consumers due to its superior quality, taste, appearance and long-grain fragrance. Import prices are typically 15–40% higher than those of locally produced rice. The NRDS aims to significantly boost domestic rice production in the coming years.

Innovations in value chains

Improved seed varieties have been the most widely adopted agricultural technology in Ghana, while other innovations have focused on soil fertility and pest management. Innovations in post-harvest processing have received less focus (CSIR et al., 2017). These seed advancements, developed through collaborations between international organizations (e.g., CIMMYT, IITA) and local research institutes (e.g., CRI, SARI), are designed to increase yields, enhance nutritional content (protein,

calcium, iron) and improve resilience to pests, diseases, drought and poor soil conditions. Many varieties, such as Ahoto and Nangbaar soybeans, enable planting during dry seasons and offer shorter maturity times. Groundnut varieties like Kpanielli and Nkatiesari deliver higher yields, faster maturation and resistance to leaf spot diseases, while cowpea varieties such as Apagbala and Marfo-Tuya improve yields, seed quality and cooking traits. Despite these advancements, knowledge gaps in input management persist, with some farmers exceeding recommended herbicide levels. Improving access to high-quality seeds and extension services is critical for optimizing input use and boosting productivity.

Key factors for scaling up agricultural innovations in Ghana include capacity building, selecting appropriate innovations, farmer participation, partnerships, policymaker engagement and marketing and funding support (Ampadu-Ameyaw et al., 2017; Egyir and Ampadu-Ameyaw, 2019; Tambo and Wünscher, 2018). A success story is the high-quality cassava flour (HQCF) initiative under the C:AVA (Cassava: Adding value to Africa) program, funded by the Bill & Melinda Gates Foundation. The program trained farmers and processors, connected stakeholders and leveraged financial and marketing support to drive adoption. Initially lacking government backing, the Ministry of Science, Technology and Innovation now promotes HQCF. Other successes include Improved Nile Tilapia and Simple Water Control Strategies for Rice Cultivation. However, some innovations, such as the Maako-Ntoose pepper variety and Azolla manure for rice, failed to scale due to limited access to seeds and other inputs, poor extension services and insufficient funding or marketing.

Farmer innovations

Farmer innovation contests in Ghana reveal that farmers are creating and applying their own solutions to address production challenges, leading to increased household wealth, greater resilience to climate shocks and reduced food insecurity. A study in Ghana's Upper East Region, one of its poorest areas, highlights how farmers independently adopt and modify techniques—such as soil conservation, crop spacing adjustments and intercropping—to boost income and food security (Tambo and Wünscher, 2016). These innovations have shortened periods of hunger and improved resilience to climate shocks, though household dietary diversity remains low (Tambo and Wünscher, 2017). The findings suggest that while resource-constrained households effectively adapt agricultural techniques, challenges persist. Participation in extension programs and collaboration with stakeholders encourage farmers to adopt and innovate further (Tambo and Wünscher, 2018). Policies should prioritize strengthening farmer knowledge, expanding access to modern technologies and improving nutrition.

Digitalization

Ghana has a thriving digital agricultural services (DAS) sector, supported by policies, private sector involvement, innovation hubs and improved digital infrastructure. Scaling these services will require investments in skills, financing and advanced technologies (Omari et al., 2020b). The country's private-sector-led telecommunications industry has grown rapidly, driven by policies promoting market liberalization and infrastructure development. Initiatives like the Ghana ICT for Accelerated Development Policy aim to modernize agriculture, enhance food security and boost agribusiness through digital tools. Ghana is a leader in DAS development in Africa, offering services such as extension support, market information, financial tools and traceability. However, many initiatives are still in their infancy and face challenges including weak policy implementation, limited digital skills, high internet costs in rural areas and inconsistent service quality. To address these barriers, efforts should focus on improving digital literacy, reducing costs, increasing funding for start-ups and investing in advanced technologies like drones and robotics.

Beyond DAS, digital technologies are widely used across the country's agricultural value chain. A survey of extension agents, input suppliers and output dealers found extensive use of digital tools to support their professional activities (Baumüller et al., 2023a; Omari et al., 2022). Mobile phones are the most commonly used tools, particularly smartphones which were used by 86% of respondents, notably extension agents and input suppliers. Extension agents employ the widest

PARI field visit to a food safety lab in Ghana

range of digital technologies, utilizing diverse mobile phone functions to interact with a broad network of value chain actors and share a variety of information. Input and output dealers primarily use digital tools to reduce transaction costs and improve networking and information exchange. However, intermediaries still prefer face-to-face interactions for certain tasks, such as training and price discussions. Digital marketing platforms could capitalize on the digital skills and networks of intermediaries to improve service delivery and enhance access to smallholder farmers in remote areas.

Employment

While public youth employment programs in Ghana have improved employment prospects, they remain small in scale, poorly coordinated and lack regular monitoring and evaluation (Ampadu-Ameyaw et al., 2020a, 2020b). Although the government has launched various initiatives to address youth unemployment, their effectiveness is limited due to short program durations, insufficient funding and duplication across ministries. Many programs are also too static, failing to adapt to technological advancements and the evolving needs of young people. The Rural Enterprise Support Programme (REP) stands out as the most effective initiative, especially in rural areas, due to its nationwide presence and administrative offices that improve outreach and service delivery. REP's success highlights the importance of accessible services, as well as factors like education, marital status, skills training and participation in youth employment programs in boosting employment prospects. To enhance youth employment, policies should focus on improving education, expanding training programs and ensuring better program coordination.

Employment growth in Ghana is increasing more rapidly in agroprocessing than in farming, highlighting the sector's potential for job creation. Unlocking this potential requires investments in training and mechanization to improve product quality and safety (Omari et al., 2020a). The food sector alone accounts for over a quarter of employment in Ghana's manufacturing subsector. A major challenge is the limited availability of skilled labour, which increases training costs for companies. Processing firms also face issues like absenteeism, theft and poor hygiene, quality and safety standards. Integrating machinery into production could enhance productivity, but barriers such as a lack of trained maintenance personnel, equipment breakdowns, insufficient funding and limited space for installations must be addressed. Greater investment is essential, not only for staff training but also to improve working conditions, including the provision of social benefits and insurance.

While local rice production in Ghana has increased employment, particularly for women, farmers need targeted support to compete with imported rice, including investments in transport infrastructure, improved rice varieties and advanced processing technologies (Ampadu-Ameyaw et al., 2018). The growth of rice production has created jobs across the supply chain, benefiting producers, processors and other stakeholders. Women, in particular, play a critical role in rice marketing and processing. However, local rice production remains uncompetitive, with consumer preferences favoring imported rice. To boost the sector's competitiveness, it is essential to invest in infrastructure that facilitates efficient transportation from rural to urban areas, improve farmers' access to high-quality rice varieties and upgrade production and processing techniques. Furthermore, investments in packaging and storage facilities are crucial to supporting local farmers and processors, enabling them to deliver products that meet market standards and consumer expectations.

Women empowerment

Women carry a disproportionate burden of unpaid work in Ghana. A fairer division of household tasks and access to time-saving technologies are essential to reducing this burden and supporting women's economic participation (Asante et al., 2024). A study on time allocation in rural Ghana reveals that women consistently spend more time on both work and unpaid activities, while girls also work more than boys. Household characteristics, such as being single-adult or low-income, significantly influence time allocation. For instance, girls in single-adult households spend more time on unpaid tasks and women in lower-income households are more likely to perform unpaid work than those in wealthier households, who have more opportunities for paid employment. Excessive unpaid labour reduces women's productivity, creating a trade-off between domestic responsibilities and economic participation. Access to tools, technologies and market opportunities can help free up women's time for paid work. These findings underscore the need for policies that promote gender equality through the redistribution of household responsibilities, investments in labour-saving technologies and initiatives to enhance women's economic empowerment, ultimately improving household well-being.

Changes in the time mothers spend on domestic and care work can negatively impact children's diets, but these effects are mitigated by the presence of substitute caregivers and access to water infrastructure (Saleemi et al., 2024). A study of market women in Ghana found that children eat less frequently and have less diverse diets on days when their mothers spend more time at the market without other caregivers at home. Access to piped water, however, can reduce these negative effects by freeing up time otherwise spent fetching water. To support women's economic participation, it is essential to provide affordable, high-quality childcare to ensure children receive proper nutrition while parents are engaged in income-generating work. Investments in water infrastructure can further alleviate women's domestic burden and enable greater workforce participation. Additionally, addressing these challenges requires shifting gender norms to promote a fairer distribution of domestic and care work. This can be achieved through education, advocacy and the promotion of positive role models.

3.6 INDIA

KEY TAKEAWAYS

Advancing agricultural innovations: Innovations like micro-irrigation, farm mechanization and digital crop management have boosted India's agricultural productivity. Expanding these requires greater public-private investment, commercialization and partnerships.

Grassroots innovations: India's Honey Bee Network shows how grassroots innovations can address local challenges and be adapted in Africa, emphasizing collaboration, training and local ownership.

Dairy sector progress: India's dairy sector supports 80 million households but needs improved feed, cold chains and financial services to enhance productivity and quality.

Poultry sector growth: Private sector-led integration in India's poultry industry enables smallholders' market access. Investments in feed, exports and environmental safeguards remain key.

Mechanization access: Tractor hire services like EM3 AgriServices help smallholders access affordable mechanization but require better infrastructure, digital literacy and seasonal planning.

Renewable energy for agriculture: Solar energy provides dual income streams, powers irrigation and reduces food waste. Expanding adoption needs subsidies, credit access and tailored programs.

Digital livestock tools: Tools like Herdman Mobile and Farmtree improve dairy productivity but face challenges with data accuracy, literacy and incentives for field staff

Innovations in value chains

Innovations in technology, institutions, and business models are boosting productivity in India's agriculture, but more efforts are needed to commercialize them, raise awareness, and assess their impact (Ganguly et al., 2017; PARI, 2017). Key innovations transforming the sector include farm mechanization, micro-irrigation, digital crop management and energy-efficient post-harvest practices. For instance, the combined use of sprinkler and drip micro-irrigation improves water use efficiency by 80–90% and is currently applied to 9 million hectares, with significant potential for expansion to crops like paddy and sugarcane. Integrating fertilizer application with drip irrigation further boosts its benefits. Jain Irrigation Systems Limited has advanced micro-irrigation through large-scale projects in states such as Karnataka and Maharashtra, achieving outcomes like a 40% increase in onion yields and a 65% reduction in water usage. To accelerate these innovations, increased public and private investment is essential, along with commercialization, knowledge exchange through farmer producer organizations and fostering political will and global partnerships. Cooperative frameworks between countries should also be explored. Additionally, public agricultural research systems must conduct comprehensive impact assessments to evaluate the benefits and challenges of these technologies.

Grassroots innovation

Grassroots innovations from India offer valuable solutions for African farmers facing similar agricultural challenges. Platforms like the Honey Bee Network have facilitated the transfer and adaptation of such innovations to African contexts (Gupta et al., 2019). For example, Kenyan farmers successfully adopted Indian-designed technologies, including a food processing machine, a seed sowing device and the Bullet Santi, a small tractor. As part of the technology transfer process, Indian innovators visited Africa to demonstrate these solutions and adapt them to local conditions. For instance, the Bullet Santi was modified for greater stability to suit African soil types. The network also provided training on assembly, supply chain management and market access. Key factors in this success included collaboration among research institutions, the social capital of the network and local ownership of the technology. To expand this model, the Honey Bee Network is supporting the creation of a similar platform in Africa. Ensuring its success will require addressing institutional challenges such as intellectual property rights and policies on grassroots innovations. Additional steps include linking students to the network, mobilizing volunteers, translating resources and leveraging social media to engage entrepreneurs and share knowledge.

Livestock

India's dairy sector showcases successful integration of small-scale producers into large-scale production through innovation, but further investment in feed, cold chains, finance and supply chains organisation is needed to address ongoing challenges (Gulati and Juneja, 2023b). The foundation for the "White Revolution" was laid during Operation Flood in the 1970s, which established a "National Milk Grid" to connect milk-surplus states with milk-deficit areas. Although the private sector entered the market later, it quickly adopted technologies to enhance dairy herd productivity and improve milk quality. Today, milk is India's largest agricultural commodity, supporting 80 million rural households, the majority of whom are women. Despite its successes, India's dairy sector still faces significant challenges. Addressing these requires better access to finance, investments in yield improvements such as feed and breeds, expansion of cold chain infrastructure and improved coordination in raw milk procurement to enhance supply chain efficiency and milk quality.

India's poultry sector shows the private sector's role in helping smallholders tackle marketing challenges with supportive policies. Further production growth requires better access to capital, quality feed, and export markets (Gulati and Juneja, 2023a). Over the past two decades, the commercial poultry sector has been the fastest-growing agricultural sector in India. This rapid growth was driven by two key factors: (1) the government's liberalization of imports for grandparent poultry stock and (2) the rise of a private sector-led vertical integration model. Through this model, large integrators and hatcheries partnered

with small farmers via contract farming arrangements. To sustain and accelerate growth, the sector will need improved access to financing to scale production and processing, better availability of high-quality feed and support for producers in meeting export market standards. Additionally, mitigating potential environmental impacts from intensification will be critical to ensuring sustainable growth.

Mechanization

India is the world's largest manufacturer of tractors, yet many smallholder farmers struggle to access them. Innovations like hiring services and "uberizing" farm machinery are helping bridge this gap by connecting farmers with tractor owners (Daum et al., 2021d; Ganguly et al., 2017; Gulati and Juneja, 2020). This approach addresses smallholder farmers' limited capacity to invest in and maintain their own equipment, particularly on small plots, while boosting agricultural productivity and affordability. A prominent example is EM3 AgriServices, a franchise offering farm machinery rentals. EM3 leverages digital tools to help tractor owners monitor and manage equipment while connecting them with farmers. With 300 hiring centers, farmers can book services via phone or in person. Another promising opportunity is the development of sensor-equipped tractors that connect to mobile platforms to gather real-time farm data on soil, water and crop conditions, optimizing input use and tracking progress.

While tractor hire services show promise in addressing mechanization constraints, significant challenges remain, particularly in digital capacities and rural tractor markets (Daum et al., 2021d; Gulati and Juneja, 2020). Barriers to digitalizing hire services include low digital literacy, distrust in prepayment via mobile apps and poor internet connectivity in rural areas. Additionally, broader issues such as inadequate infrastructure (e.g., underdeveloped roads), limited tractor supply and seasonal demand fluctuations impede the efficiency of local tractor markets, regardless of digital tools. To address these challenges, policies should prioritize improving digital literacy through visual aids in mobile applications and building trust with features like customer ratings. Booking agents can serve as intermediaries while digital capacities remain low. To reduce "idle capacity" outside peak seasons, tractor owners could offer diversified mechanization services year-round or operate across agro-ecological zones. Strengthening the enabling environment through investments in rural roads, connectivity, equipment and a stronger legal framework can further enhance mechanization access.

Digitalization

In India, digital tools have significant potential to address constraints in livestock production, helping to reduce poverty, ensure food security and enhance environmental sustainability (Daum et al., 2022c). Most tools in the livestock sector focus on dairy, with limited options for pastoralists. Examples include Herdman Mobile, which uses QR codes to track animal health and fertility while supervising field staff and Farmtree, which helps farmers manage herds with a focus on fertility and economic efficiency. These tools, ranging from text messaging to advanced mobile apps, have improved dairy productivity for farmers and companies. However, challenges persist, such as field staff lacking incentives to record key data, farmers providing inaccurate or incomplete information and literacy barriers limiting usability. Further investment in research to develop advanced digital tools and ensure the protection of farmers' data is crucial for advancing digitalization in the dairy industry.

Skill development

India's government has prioritized skill development to build a modern workforce, but more emphasis needs to be placed on innovation capacities to enable workers to adapt to evolving technologies in agricultural supply chains (Ganguly et al., 2019). Much of India's food and agriculture workforce remains undereducated and lacks formal or informal training. Policies emphasize making skill development programs aspirational for youth, recognizing prior experience and ensuring quality training, assessment and certification to enhance job market competitiveness. While the government plays a key role in designing and funding initiatives, private sector involvement has expanded their scope and sustainability. To modernize agriculture and boost employment, training programs should focus on innovation across value chains to foster technology adoption, value chain management and sustainable practices. Cost-effective outreach models—such as classroom training, farmer field schools and e-platforms—can broaden access to high-quality skills training for a diverse audience.

Renewable energy

Energy solutions for rural India must be tailored to local contexts and link agricultural production with energy use, such as through decentralized bioenergy markets (PARI, 2019e). Rural households often rely on unreliable, inefficient and harmful energy sources and transitioning to modern alternatives remains challenging due to mismatched policies and local needs. For instance, households that traditionally use cattle dung for bioenergy are less likely to adopt subsidized liquefied petroleum gas (LPG). In such cases, modern bioenergy stoves or biogas systems may be more suitable alternatives. Decentralized bioenergy markets can further promote modern cooking energy by enabling households with surplus residues to sell them to local energy providers. Education programs, particularly for women and girls and awareness campaigns are also critical to supporting the adoption of modern energy solutions.

The Indian government's ambitious goals of achieving 500 GW renewable energy capacity by 2030 and doubling farmers' incomes are interlinked and can only be realized if pursued simultaneously (Gulati et al., 2016). Solar power can play a pivotal role in meeting both targets. Integrating solar energy into agriculture offers significant opportunities. For example, installing solar panels 15 feet above agricultural fields allows farmers to grow crops underneath, creating dual income streams. Solar power can also be leveraged for irrigation by replacing electric pumps with solar-powered ones. Connecting these pumps to the grid would give farmers greater control over energy usage while reducing energy subsidies, which could be redirected to subsidize solar pump purchases. Expanding

solar energy to cold chains could further reduce food waste and increase renewable energy consumption. Measures to make solar technologies more affordable for farmers may include upfront payments, subsidies and improved access to low-interest credit.

3.7 KENYA

KEY TAKEAWAYS

Improved seed systems: Adoption of improved seeds in Kenya remains low. Strengthening decentralized seed systems, improving seed certification and ensuring distribution through trusted networks are essential to rebuilding trust and boosting adoption.

Farmer innovation: Kenyan farmers develop cost-effective innovations and adapt Indian technologies via platforms like the Honey Bee Network. Support for commercialization, women's participation and local ownership is crucial.

Mechanization in production: Adoption of agricultural machinery in Kenya remains limited due to high costs and lack of financing. Expanding access to machinery, improving repair services and supporting the local manufacturing sector are key to addressing these barriers.

Mechanization in processing: Mechanization and automation in Kenya's food and beverage manufacturing sector boosts efficiency, quality and reduces waste. Addressing skill gaps through targeted training and social safety nets is essential for worker adaptation.

Digitalization: Kenya is a leader in agricultural digital services (DAS), such as M-Pesa and Twiga Foods, but scaling requires improving rural internet access, digital literacy and affordability challenges.

Youth and skill development: Many Kenyan youth see farming as part of mixed livelihoods rather than a sole occupation. To support this, policies should promote vocational training, practical skills and entrepreneurship, ensuring youth are prepared for modern agriculture.

Selected value chains

The sweet potato and milk value chains were initially selected for Kenya's GIC (KALRO et al., 2017). **Sweet potato** is a significant part of Kenya's diet, serving as a substitute for maize, the country's staple food (Makini et al., 2018a). Urban demand for sweet potato has steadily grown and production has increased due to improved cultivars and farming techniques. However, sweet potato cultivation remains small-scale and post-harvest losses pose a significant challenge, keeping outputs low.

Dairy is critical for food security, nutrition and rural livelihoods. It is a major income source for many Kenyan smallholder farmers, although production remains low at approximately 5.46 liters per cow per day. The sector is well-organized and dominated by processors along the supply chain. Around 6% of Kenyan households engage in dairy farming, contributing to job creation in agro-processing industries.

Innovations in value chains

The cultivation of Orange Fleshed Sweet Potato (OFSP) has expanded in Kenya through a multi-stakeholder initiative. To further support OFSP, policies should promote marketing, value-addition centers and the involvement of health actors for outreach (KALRO et al., 2017). KARI (now KALRO)-Kakamega, in collaboration with CIP and local farmers, strengthened the OFSP value chain in Busia and Bungoma districts to combat vitamin A deficiency, involving farmers, seed multipliers, traders, extension agents, processors, media and community organizations. Activities included developing technologies, improving planting material production, providing agronomic training, pest and disease management and training in post-harvest handling, storage and marketing. These efforts transitioned OFSP cultivation from subsistence to commercial levels, releasing 17 superior varieties between 2008 and 2013. A multi-level multiplication strategy boosted root yields from 10 to 30 tonnes per hectare.

Adopting improved fodder can significantly boost productivity in Kenya's dairy sector, increasing smallholder farmers' incomes and doubling household milk consumption (KALRO et al., 2017). Despite the importance of dairy farming as a key income source, average daily milk production per cow remains low due to poor animal husbandry and feeding practices. To address this, a USAID-supported innovation introduced practices to enhance fodder production and conservation, including high-nutrient indigenous grasses, improved grass varieties and protein-rich legumes. The initiative's success is attributed to USAID's financial and technical support and the collaborative learning culture within dairy farming communities. To further scale productivity, recommendations include promoting innovations, encouraging farmer groups to engage in commercial dairy feed production, adopting technologies like Total Mixed Rations and strengthening partnerships among farmers, development partners and national governments.

Improved seeds have the potential to boost agricultural productivity, enhance nutrition and meet consumer preferences, yet many Kenyan farmers remain reluctant to adopt new hybrid varieties (Christinck et al., 2018; PARI, 2019a). Seeds with novel traits, such as earlier-maturing varieties for relay cropping or those better adapted to changing moisture and temperature conditions, offer promising options for farmers and their market partners (KALRO et al., 2017). Despite these benefits, adoption in Kenya has been low. Key reasons include concerns over poor seed germination and the widespread presence of counterfeit seeds in the market, which undermine farmers' trust in hybrid varieties.

Farmer organizations in Kenya play a key role in advancing agricultural development but face several challenges that limit their potential (Wortmann-Kolundžija, 2019). One major issue is limited access to relevant market information, which weakens their competitive advantage. Additionally, the structure and size of these organizations can impact member commitment and engagement. Social factors such as trust and fostering an entrepreneurial mindset also play a crucial role in their performance. To function effectively, farmer organizations must align their activities with clear objectives and member needs. Adopting best practices, encouraging community participation and building structural social capital—such as stronger value chain connections—can enhance collective power and motivate members to engage more positively.

Farmer innovations

Kenyan farmers have demonstrated strong innovation capacity to address agricultural production challenges. Support is needed to validate these innovations, assist with commercialization and empower women innovators (Tambo, 2018). A farmer innovation contest organized by PARI highlighted a wide range of innovations, particularly in livestock production, crop management and storage. Most innovations (79%) adapted existing technologies to better suit local conditions, while the others were entirely original. Key drivers of innovation included curiosity, reducing costs, increasing production and improving quality. Farmers typically invested minimal financial resources (USD 20 or less) in developing these innovations. Most innovators reported improved yields and reduced production costs and almost two thirds knew others who had adopted their ideas. However, more support is needed to validate innovations and commercialize those with market potential. Women innovators were underrepresented, contributing only 30% of submissions. Greater efforts are required to encourage women's participation and showcase their contributions.

Platforms like the Indian Honey Bee Network have facilitated the transfer and adaptation of grassroots innovations to African contexts (Gupta et al., 2019). Kenyan farmers successfully adopted such innovations, including a food processing machine, a seed sowing device and the Bullet Santi, a small tractor. As part of the technology transfer process, Indian innovators visited Africa to demonstrate these solutions and adapt them to local conditions. For instance, the Bullet Santi was modified for greater stability to suit African soil types. The network also provided training on assembly, supply chain management and market access. Key factors in this success included collaboration among research institutions, the social capital of the network and local ownership of the technology. To expand this model, the Honey Bee Network is supporting the creation of a similar platform in Africa. Ensuring its success will require addressing institutional challenges such as intellectual property rights and policies on grassroots innovations. Additional steps include linking students to the network, mobilizing volunteers, translating resources and leveraging social media to engage entrepreneurs and share knowledge.

Livestock

Kenya's dairy sector is vital for food security, nutrition and income generation but faces structural challenges that hinder its full potential (Makini et al., 2019; Mose et al., 2020). Key issues include limited access to improved breeds, high feed costs, inadequate pastures and fodder, low-quality livestock nutrition, diseases, pests, droughts and weak extension and veterinary services, particularly in the camel value chain. To address these constraints, several innovations have been proposed:

- A low-cost breeding program using artificial insemination (AI) to improve breeds, though awareness about AI's benefits remains limited.
- Strengthened extension services and farmer training on conserving feed resources, especially for pastures affected by drought.
- Development of nutrient-rich hay and crop varieties, such as indigenous grasses and protein-rich legumes.
- Community-led initiatives to prevent rangeland degradation caused by overgrazing.
- Enhanced veterinary services and improved collection infrastructure, including cooling facilities and transport.
- Focus on quality and food safety, particularly within formal marketing channels.

Research in these areas is therefore imperative to identify strategies to address these challenges (Makini et al., 2019).

Innovations in Kenya's milk supply chain could boost productivity and reduce food safety hazards, including cold chain technologies and solar power (Salvatierra Rojas et al., 2018). Smallholder farmers typically supply milk to cooperatives, which collect and deliver it to dairy plants. However, poor hygiene practices and the lack of cooling systems at farms and cooperatives increase the risk of microbial contamination. A solar-powered milk cooling system offers a cost-effective solution, preserving milk quality for 6 to 16 hours and reducing food safety risks. This innovation is especially suitable for off-grid areas, utilizing renewable energy. Farmers also benefit from reduced milk losses and higher prices, increasing their incomes. Despite its potential, challenges such as ice availability, maintenance costs and limited supply of solar cooling units must be addressed to scale up this innovation.

Aquaculture

Kenya's aquaculture sector, though small compared to global standards, highlights the impact of government commitment and international competition on production growth (Hinrichsen et al., 2022; Walakira et al., 2023). As the eighth-largest aquaculture producer in Africa by volume, the sector experienced rapid growth between 2010 and 2014, driven by the Economic Stimulus Program (2008–2014), which led to a five-fold increase in production. However, growth slowed after the program ended and governance devolved in 2013, shifting aquaculture responsibilities to counties, many of which deprioritized the sector. Since 2019, production has rebounded due to rising domestic demand and large-scale

commercial investments. However, cheap frozen imports, particularly from China, pose economic challenges for local producers. Kenya's experience underscores the need for targeted government policies to support aquaculture. Short-term solutions include fostering private sector engagement, improving access to affordable feeds and fingerlings and addressing logistical hurdles for domestic producers.

Mechanization

Mechanization in Kenya's crop production remains limited due to institutional and structural barriers (Makini et al., 2017, 2020b). In key sectors like banana and rice, mechanization is mostly used for land preparation (ploughing and harrowing) and transport. A major challenge is funding, as most farmers purchase tractors using personal savings or loans, while publicly-owned tractors are funded through government grants. With no subsidies for tractor financing, commercial banks play a leading role in providing credit. Publicly-owned tractor users are more likely to benefit from after-sales services compared to those with privately-owned tractors. To promote mechanization, measures are needed to expand access to machinery dealers, increase financial resources and strengthen extension services.

Mechanization and automation are widely adopted in Kenya's agroprocessing sector. The new technologies have shifted workers' tasks rather than causing significant job losses, necessitating training to help employees adapt (Baumüller et al., 2023b). A survey of manufacturers revealed that all firms use machinery for processing and packaging and 85% employ computer-controlled automation, with most equipment imported from Europe and Asia. Reported benefits include improved product quality, greater efficiency, cost savings and reduced food waste. While 67% of firms consider their staff qualified to operate these systems, skill gaps in technical and computer skills persist. Automation has not led to widespread job cuts—only 27% of firms reduced staff after major investments, while 45% reported job gains. Workers, particularly in automated firms, are often reassigned to new tasks. To help workers adapt to evolving technologies, targeted training programs to build technical skills are crucial, along with social safety nets to address potential job losses.

Mechanization training in Kenya is offered at various education levels, but more practical training and stronger industry linkages are needed to enhance educational opportunities (Makini et al., 2020b). Training is primarily conducted in universities and technical and vocational training (TVET) colleges, offering both long- and short-term courses. Public institutions generally have more experience, better infrastructure and greater course flexibility compared to private institutions. Universities focus on agricultural engineering, while TVET colleges offer certificates and diplomas in automotives and mechanical engineering. Enrollment in these programs is predominantly male. Students feel that more time should be allocated to college programs and internships and industry partnerships should be expanded to better align training with market needs.

Kenya's agricultural machinery manufacturing sector is small but growing, with potential to compete with imports through improved skills, regulated imports, reduced costs and assured quality (Kamau et al., 2022a). A survey of machinery manufacturers for crop production, post-harvest handling and livestock production found that most enterprises are privately owned and cater to smallholder farmers. To reduce market risks, 62% of manufacturers produce machines on demand, focusing on post-harvest equipment like forage choppers, milling and shelling machines, while tractors are predominantly imported. Most companies offer on-the-job training, but few are affiliated with local education institutions. To boost competitiveness, measures should include reducing electricity prices and taxes, improving access to finance, strengthening links with training institutes, regulating foreign machinery imports, enforcing quality certification standards and offering business skills training.

Digitalization

Often referred to as the Silicon Savannah, Kenya is a leader in agricultural digitalization, supported by government policies, innovation hubs, angel investors and a tech-savvy population (Makini et al., 2020a). The mobile payment system M-Pesa is the most successful mobile money platform in Africa and Kenya hosts the largest number of digital agricultural services (DAS) on the continent. One prominent example is Twiga Foods (Mulinge et al., 2024a), a company leveraging digital technologies to coordinate sourcing from smallholder farmers and supply products to small vendors in Nairobi. This innovation has improved supply chain efficiency, reduced marketing risks for farmers and stabilized prices. However, to reach farmers effectively, Twiga Foods depends on a network of agents, underscoring the critical role of human intermediaries in managing the first mile and building trust with farmers.

Despite successes, only a few digital agricultural services (DAS) in Kenya have reached scale, with most remaining small and fragmented. Scaling up DAS requires a user-centric approach that addresses user preferences and needs (Kieti et al., 2022, 2021). Key factors for users include tool efficiency—such as easy access to information—and loyalty, driven by the platform's quality and reliability. Policies should focus on expanding DAS accessibility, raising awareness of their benefits and ensuring affordability. Additionally, improving infrastructure and building user capacity through skills training are essential. Lessons from Kenya's dairy sector emphasize that DAS success also depends on broader conditions within which they operate, such as access to feed and transport infrastructure (Bateki et al., 2021; Daum et al., 2022c).

Beyond DAS, digital technologies are widely used by extension agents, input suppliers and output dealers in Kenya to support their activities (Baumüller et al., 2023a; Kamau et al., 2022b). Mobile phones, particularly smartphones, are the most commonly used tools, with 76% of respondents—mainly extension agents but also dealers—reporting their use. Extension agents employ the broadest range of digital technologies, leveraging mobile phone features to interact with value chain actors and share diverse information. Input and output dealers primarily use digital tools to lower transaction costs and improve networking and information exchange. However, intermediaries still prefer face-to-face interactions for tasks such as training and price discussions. Digital marketing

platforms could build on the digital skills and networks of intermediaries to enhance service delivery and expand access to smallholder farmers in remote areas.

Further up the value chain, digital technologies are widely adopted in Kenya's agroprocessing sector, particularly through computer-controlled automation (see section above). This demonstrates the transformative potential of digital technologies across the entire food and agriculture sector, extending beyond agricultural production.

Skill development

Kenya is implementing national strategies to reform ATVET. While students generally report satisfaction with training quality, further investments in practical training and efforts to engage more women are needed (Mulinge et al., 2024b). A survey of students in agricultural training programs revealed that most participants come from rural farming backgrounds. About half of them aim to work in private, public, or third-sector extension services, while others aspire to become agripreneurs or ministry staff). Most students find the training relevant and of good quality, with widespread use of digital tools. However, many expressed a desire for more hands-on, practical components in their courses. Women remain underrepresented in the ATVET system, accounting for only 39% of surveyed students and 30% of teachers, highlighting the need for targeted efforts to close the gender gap in agricultural education.

Youth aspirations

Contrary to the common belief that young people are disengaged from agriculture, many Kenyan youth are open to participating in the sector, particularly as part of mixed-livelihood strategies (LaRue et al., 2021). Binary questions about farming, such as full-time farming versus no farming, can be misleading, as studies framed this way often conclude that youth prefer livelihoods outside farming. A survey of Kenyan youth revealed that most envision farming playing a role in their future, though few aspire to farm exclusively. Instead, they see farming as one component of a mixed livelihood strategy, combining income from both on-farm and off-farm activities. Agricultural policies and programs for youth should recognize this flexibility, supporting the linkages between these livelihood pillars—for example, using income from farming to fund business investments and vice versa. This calls for more holistic policy approaches that reflect the realities of youth livelihoods.

Focus group discussions with Kenya farmers

3.8 MALAWI

KEY TAKEAWAYS

Boosting soil fertility: **Restoring soil fertility in Malawi through conservation agriculture, intercropping and improved seeds and fertilizers is key to enhancing productivity and reducing rural poverty.**

Farmer innovations: **Malawi's farmers create cost-effective, locally adapted solutions, particularly in crop and livestock production. Greater support is needed for validation, commercialization and encouraging women's participation.**

Youth in agriculture: **To increase the attractiveness of agricultural professions for Malawi's youth, efforts should prioritize land access, crop innovations, stronger extension services and improved infrastructure like roads and electricity.**

Selected value chains

The soya, cassava and groundnut value chains were initially selected for Malawi's GIC (DARS et al., 2017). **Soybean** production in Malawi primarily supports animal feed for aquaculture and poultry farming, with growing demand presenting significant opportunities for growth despite suboptimal yields. Soya oil is also a key import, making up 8.3% of import value. Additionally, soybeans are valued for institutional food programs, such as hospital meals, due to their nutritional benefits.

Cassava is gaining prominence as a cash crop, meeting rising national demand. Farmers are increasingly cultivating cassava for its drought tolerance, adaptability to marginal soils, pest and disease resistance, low labour requirements and stable yields.

Groundnuts are Malawi's second most cultivated cash crop and the fourth largest export crop. Their production is expanding as the government provides inputs and support, particularly in areas transitioning from tobacco farming, which is in decline. However, concerns over aflatoxin contamination remain a significant challenge.

Innovations in value chains

Restoring soil fertility and adopting soil-related innovations are critical for improving agricultural productivity in Malawi. Other key innovations include the use of improved seeds, fertilizers and conservation agriculture practices (DARS et al., 2017). Land degradation, particularly increasing soil acidity, is reducing potassium and phosphorus levels, further diminishing fertility and productivity. Conservation agriculture, which promotes minimal soil disturbance, permanent soil cover and crop diversification, can help restore soil organic matter. Intercropping, such as combining cassava with cowpeas, pigeon peas, or crotalaria, reduces pests and maintains nitrogen levels, while crop rotation improves soil quality.

Practices like maize-soybean rotations with faidherbia albida trees and using legumes or plant waste as ground cover have shown positive effects. Small tractors can also be used to incorporate organic matter into the soil. To encourage adoption, policies should incentivize conservation agriculture and intercropping while prioritizing improved seeds and proper fertilizer use. Training farmers on fertilizer application can optimize its benefits. In the maize value chain, improved seeds and fertilizers can significantly boost productivity, contributing to GDP growth and reducing rural poverty (Mathenge et al., 2019).

Farmer innovations

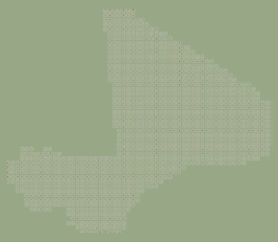
Farmers in Malawi are a valuable source of locally adapted innovations. Support is needed to validate these innovations, assist with commercialization and empower women innovators (Tambo, 2018). A review of submission to a farmer innovation contest organized by PARI revealed that over half of farmers developed original innovations, while the rest adapted technologies to local conditions. Most innovations aimed to increase agricultural production and reduce costs, with technical innovations dominating in livestock production, crop management and storage. These innovations were cost-effective, relying on locally available materials costing USD 20 or less. Although two thirds of innovators knew others who had adopted their ideas, further support is required to validate and commercialize promising innovations. Women were underrepresented, contributing just a quarter of submissions. Efforts are needed to encourage women to innovate and to highlight their contributions.

Farmer innovator from Malawi

Employment

Engaging young people in Malawi's national job creation programs has the potential to significantly reduce unemployment, particularly in rural areas. Challenges such as limited coordination, training and funding must be addressed to fully realize this potential (Gondwe et al., 2020). A large proportion of Malawian youth work in low-quality, informal jobs due to limited opportunities. Over the past 15 years, public and private initiatives have sought to involve young people in agricultural value chains to boost employment. However, these programs primarily focus on rain-fed agriculture and conservation farming, often creating temporary jobs and leaving many unemployed during off-seasons. Most programs emphasize crop cultivation training and inputs but neglect other critical skills. Key barriers to success include poor coordination among agencies, insufficient funding and weak monitoring mechanisms. To attract youth to agriculture and create sustainable opportunities, it is essential to address these issues. Efforts should focus on improving access to land, introducing innovations and technologies in crop production, strengthening extension services and upgrading infrastructure such as electricity and roads.

3.9 MALI



KEY TAKEAWAYS

Rice sector innovations: Advances in disease-resistant varieties, crop management and processing, such as turning broken rice into flour, have boosted Mali's rice productivity and market access, benefiting farmers, especially women.

Irrigation systems: Drip, sprinkler and Californian irrigation systems improve water efficiency and productivity in Mali, offering significant growth potential for high-value crops like fruits and vegetables.

Livestock challenges: Livestock productivity in Mali is hindered by limited feed, poor veterinary services and market gaps. Improved feeds, veterinary systems and vocational training are key to enhancing the sector.

Seed systems: Strengthening local seed production, storage and ECOWAS regulations can reduce Mali's reliance on imported seeds and improve access to high-quality, pest-resistant varieties.

Mechanization: Government subsidies and local manufacturers are expanding mechanization in Mali, but high costs, limited capital and skilled labour shortages must be addressed to scale adoption.

Digital technologies: Mobile technologies are widely adopted by extension agents and dealers in Mali, improving networking, reducing transaction costs and facilitating information exchange across agricultural value chains.

Vocational training: Agricultural training programs in Mali are expanding but require greater investment in digital skills, practical learning opportunities and efforts to increase women's participation to meet the sector's needs effectively.

Selected value chains

The rice, mango and potato value chains were initially selected for Mali's GIC (IER et al., 2017). **Rice** is Mali's most important commercial crop, contributing 10.6% of agricultural value and 5% of GDP (Diarra, 2019). However, the sector faces challenges such as low private investment, inadequate processing (leading to a high proportion of broken rice grains) and poor coordination among sub-sectors.

Potatoes are traditionally grown in regions like Sikasso and Kati, with rising demand driven by population growth and changing consumer preferences. The value chain is dominated by seed importers (mainly from Europe), producers and traders.

Mangoes are Mali's most popular fruit and play a vital socio-economic role. Mango production provides rural employment and generates income through exports, primarily to European distribution chains (Kergna et al., 2018a).

Innovations in value chains

Innovations to improve rice productivity, quality and cost-effectiveness in Mali present significant growth opportunities for the sector (IER et al., 2017). These include the development of disease-resistant rice varieties and technologies for efficient crop management, such as soil preparation, fertility enhancement and pest control:

- One notable initiative by Africa Rice repurposes broken rice—traditionally considered low-value—into a flour substitute for pastries, blending rice and wheat flour to create a competitive product. Advances in processing technologies have further increased the commercial value of broken rice.

- The "Crédit stockage villageois" scheme is another important innovation, offering a credit and storage system for rice farmers. This enables them to store crops post-harvest and benefit from higher market prices, with strong participation from women farmers.

- Ridge tillage has proven effective, increasing water infiltration by 10% of annual rainfall (around 800 mm) and boosting cereal yields (including millet, sorghum and maize) by 30% on average, with over 50% gains in dry years.

Biofortification enhances nutrition by increasing essential nutrients like iron and zinc in crops (IER et al., 2017). The McKnight Foundation, in collaboration with national institutes like IER, has supported research to improve nutrition through biofortification of locally diverse crops. One key initiative was the International Sorghum and Millet Collaborative Research Support Program (INTSORMIL CRSP), funded by USAID, which aimed to improve food security in Mali. The program focused on seed multiplication, on-farm testing and variety exchange for sorghum and millet, identifying optimal cultivars while promoting fertilizer use and best agricultural practices. This multidisciplinary effort involved scientists, educators and organizations from Burkina Faso, Mali, Niger, Nigeria, Senegal and the U.S., addressing the entire value chain. The project provided training, improved seeds, fertilizers and resource management techniques. It also supported technology transfer to entrepreneurs and processors, enabling the production of diverse products such as sorghum flour, couscous, biscuits and poultry feed.

Small-scale irrigation systems have significant potential in Mali, offering greater water efficiency and improved land productivity compared to traditional methods (Kergna et al., 2018a). With agriculture heavily reliant on rainfall, better water management could transform the sector. Mali's water resources are considerable, with the Senegal and Niger rivers providing 70 billion cubic meters annually and groundwater reserves estimated at 2,700 billion cubic meters, of which 66 billion cubic meters are renewable each year. However, these resources remain underutilized. In urban areas, the Californian irrigation system is common for vegetable production, using surface or groundwater distributed through furrows. Sprinkler irrigation, typically employed on commercial farms for high-value crops like fruit trees, maximizes water efficiency. Drip irrigation, delivering water directly to crops at low pressure, is primarily used by wealthier farmers growing fruits and vegetables. These small-scale systems are cost-effective and greatly enhance agricultural productivity.

Livestock

Livestock, particularly small ruminants, play a critical role in Mali's rural economies. Investments in infrastructure, feed, breeds, veterinary services and market information are needed to boost the sector (Dembele et al., 2022; Kergna and Niallibouly, 2020). Over 90% of households engage in livestock keeping. To assist them, technologies such as improved feed rations, pastoral perimeters and genetic enhancements have been introduced. The Livestock Market Information System also provides valuable market insights. However, these innovations must be supported by high-quality veterinary services, which research shows are essential for boosting livestock productivity. Policies should prioritize subsidizing animal feed, improving water supply and encouraging the establishment of small processing units in key livestock zones to increase access and efficiency. Strengthening livestock keepers' capacity through vocational training and networking is equally important. Investments in infrastructure, market creation and capacity building are crucial for enhancing the sector's economic potential, reducing poverty, improving food security and promoting nutrition.

Seed systems

Irish potato production in Mali is hampered by limited access to improved seeds, inadequate seed storage and conservation infrastructure and shortages of labour and credit. Investing in local infrastructure could help address these challenges (Kergna and Dembélé, 2017). Mali heavily relies on seed imports, making it difficult for farmers to afford the quantities needed for optimal productivity, with average yields estimated at 20–25 tons per hectare. Most potatoes are sold in domestic markets, with the remainder exported to countries like Côte d'Ivoire, Burkina Faso, Ghana, Togo and Senegal. To improve pest and disease resilience—particularly against bacterial wilt (Ralstonia solanacearum) and scab threadworm (Meloidogyne sp.)—increased investment in the seed sector is essential. Developing local seed supply infrastructure and establishing common ECOWAS legislation

on seed production, multiplication and certification are also critical for ensuring high-quality, high-yield potato production.

Decentralized seed production and distribution systems with shorter delivery chains have the potential to strengthen seed systems in Mali (Christinck et al., 2018). Although Mali operates within a weak regulatory framework, its short seed supply chains contribute to ensuring both seed availability and quality. This system also allows seed-producer cooperatives to sell leftover stocks as grain, reducing waste and improving efficiency. To further enhance these seed systems, research and investment should focus on two critical areas: (a) treating seeds closer to the time of sale to preserve their quality and (b) developing decentralized seed production and distribution networks with shorter delivery chains.

Herbicides

The use of herbicides for weed control has increased in Mali in recent years, driven by lower prices and improved availability. While the chemicals have decreased labour demand, the have also raised environmental and health concerns (Kergna et al., 2018b). Herbicides have reduced the need for hand weeding—freeing up time for women, who traditionally perform this task—and cutting weeding labour costs by up to 50%. To address potential environmental and health concerns, policies should focus on monitoring the herbicide supply to ensure the quality and safety of both registered and unregistered products on the market. Additionally, improving knowledge and training on the proper use and application of herbicides is essential to mitigate their negative impacts.

Mechanization

Agricultural mechanization is growing in Mali, with tractor numbers nearly doubling between 2014 and 2021 due to government subsidies, but machinery remains too costly for many smallholders (Kergna, 2018; Kergna et al., 2020). Structural barriers also continue to hinder the scaling up of mechanization. The "Stratégie de mécanisation agricole au Mali," introduced in 2008, identified persistent challenges faced by local manufacturers, including low productivity, difficulty competing for public contracts and high raw material costs, worsened by steep customs duties (Daum, Adegbola, Kamau, et al., 2022). To promote agricultural growth and strengthen the mechanization sector, the government must establish policies and create an enabling environment that improves smallholders' access to machinery and inputs. Supporting local manufacturers by enhancing their capacity and skills in machinery use and repair, improving access to finance and implementing fairer tax regimes is also critical.

Since the 1980s, local agricultural machinery manufacturing has been growing in Mali to provide farmers with affordable, high-quality tools, but improved access to production equipment, financing, reliable electricity and skilled labour is required for scaling (Kergna et al., 2022). Policy initiatives, such as the Agricultural Orientation Law and the Agricultural Sector Investment Plan, have supported this growth by promoting traditional and industrial manufacturing for family farmers. A survey of machinery manufacturers shows most companies are privately owned, with over 60% inherited and others established as personal ventures. Manufacturers primarily produce machines for crop production and processing, including ploughs, direct seeders, harrows, milling machines and trailers, while larger equipment like tractors is mostly imported. However, the sector faces significant challenges, including limited access to capital, machines and land, as well as unreliable electricity and high energy costs, which vary by location. Additionally, a shortage of skilled artisans and reliance on rudimentary tools hinder progress. Addressing these obstacles is essential for the sector's growth.

Digitalization

Digital technologies are widely used by extension agents, input suppliers and output dealers in Mali to support their professional activities (Baumüller et al., 2023a). A study shows that mobile phones are the most commonly used tools, particularly smartphones which are used by 71% of respondents, in particular extension agents, but also dealers. Extension agents employ the widest range of digital technologies, utilizing diverse mobile phone functions to interact with a broad network of value chain actors and share a variety of information. Input and output dealers primarily use digital tools to reduce transaction costs and improve networking and information exchange. However, intermediaries still prefer face-to-face interactions for certain tasks, such as training and price discussions. Digital marketing platforms could capitalize on the digital skills and networks of intermediaries to improve service delivery and enhance access to smallholder farmers in remote areas.

Skill development

While students are generally satisfied with the quality of ATVET in Mali, investments in practical training, digital skills, school facilities and women's participation are needed (Kergna and Nientao, 2024). Mali is advancing agricultural skills through its National Policy for Vocational Training. A survey of students in agricultural training programs shows that over half come from rural, farming backgrounds. Many aim to become agripreneurs, work in extension services, or join agricultural research organizations, with fewer aspiring to government jobs. Most students feel the courses meet their needs, cover relevant topics and are taught by qualified, approachable teachers. However, they highlighted gaps in digital skills training, insufficient time and resources for practical work and poor access to facilities such as internet, computers and literature. Women remain underrepresented, accounting for only 35% of students and 8% of teachers in ATVET programs. Addressing these gaps will require additional public investment in infrastructure, teaching materials and targeted efforts to engage women.

3.10 NIGERIA

KEY TAKEAWAYS

Scaling innovations through platforms: Innovation platforms in Nigeria improve access to seeds, pest control and training. For example, cassava platforms benefit women and smallholders, while rice platforms link farmers to improved varieties and processors.

Livestock growth: Improved feed systems and infrastructure are needed to boost productivity and profitability in Nigeria's livestock sector, alongside policies to reduce feed costs and strengthen veterinary services.

Mechanization growth: The private sector drives mechanization, but challenges like limited capital, poor infrastructure and inadequate training persist. Investments in transport, maintenance, vocational training and supportive policies are essential to boost progress.

Digitalization: Nigeria's agricultural digital services remain underdeveloped. Improving connectivity, digital skills and rural infrastructure is key to scaling platforms like AgroMall, which connects farmers to buyers and inputs.

Aquaculture potential: Investments in feed, fingerlings and infrastructure can help Nigeria's aquaculture meet domestic demand, reduce imports and strengthen food security.

Selected value chains

The maize, rice, cassava and potato value chains were initially selected for Nigeria's GIC. Nigeria is Africa's largest maize producer, with maize being the second most widely cultivated crop in the country. A significant portion of maize is used for processed products (ARCN et al., 2017).

Nigeria is also the largest **rice** producer in West Africa, but low productivity compared to neighboring countries leaves the nation heavily reliant on imports, primarily from India, China and Thailand, to meet demand. To achieve self-sufficiency in rice production, the government is implementing policies to boost productivity in the sector.

Additionally, Nigeria is the world's leading **cassava** producer, a crop widely cultivated by smallholder farmers. Cassava serves as both a staple food and a critical industrial raw material (Phillip et al., 2018b).

In contrast, ***potatoes*** account for only 1% of Nigeria's total agricultural output. Potato yields are among the lowest globally due to cultivation in marginal areas. However, growing urban demand is driving expansion in potato production.

Innovations in value chains

Limited access to finance, inputs, labour, transportation and markets hinder agricultural productivity growth in Nigeria, particularly in the cassava and rice sectors (Philip et al., 2018; Phillip et al., 2018b). Additional factors contributing to low productivity include inadequate irrigation and market infrastructure, underinvestment in research and extension services, fluctuating exchange rates and restricted access to credit for essential inputs and services, such as processing, storage and transportation.

Innovation platforms are effective tools for scaling agricultural innovations in Nigeria by improving access to seeds, pest control, training and markets (Philip et al., 2018, 2016). A notable example focuses on cassava production, engaging stakeholders such as local governments, NGOs, private sector actors and research institutions such as the International Institute of Tropical Agriculture, the National Root Crops Research Institute, ARCN and the Agricultural Research Council of Nigeria. Through these platforms, farmers gain access to disease-resistant cassava varieties that combat Cassava Mosaic Disease, a major cause of post-harvest losses. Farmers also receive training on post-harvest practices and are connected to private agro-processors and markets. In Abia State, the number of beneficiary cassava farmers rose from 100 to 450,000 in just one year (2009–2010). Women, who make up 70% of cassava cultivators in the state, have particularly benefited. Similarly, innovation platforms have facilitated the distribution of improved rice varieties like FARO 44, FARO 52 and FARO 54 by linking farmers to private agro-processors.

Social capital innovations, such as farmers' groups, have empowered rural Nigerian households to invest in their farms and improve their livelihoods (Phillip, Jayeoba, and Ndirpaya, 2018). Under the National Fadama Development Project, these groups help farmers access credit and productive assets by pooling resources. This collaborative approach enables members to purchase equipment and save 10% of their net sales for asset maintenance, leading to higher incomes and reduced poverty. For cassava production, farmers have acquired tools like sprayers, wheelbarrows, cassava lifters and first aid kits. In rice production, groups have purchased water pumps, generators, milling machines and threshers (Philip et al., 2018). Implemented in partnership with the World Bank and local governments, this program has been scaled up to all 36 states in Nigeria.

Livestock

Grazing, supplemented with crop residues, forages and fodder shrubs, is the most profitable feeding regime for Nigerian pastoralists (Obayelu, 2023). Exclusive grazing for dairy animals also results in higher average milk productivity compared to other feeding methods. To unlock the full potential of Nigeria's livestock sector, significant improvements are needed in feed mills and the development of the livestock feed value chain. Additionally, establishing feed safety standards is essential. These infrastructure upgrades should be paired with policies aimed at reducing feeding costs to ensure sustainable growth in the sector.

Aquaculture

Nigeria has one of the largest aquaculture sectors in Africa, yet production volumes fall short of meeting demand. Investments in feed, fingerlings and infrastructure, guided by development plans, are crucial to help producers seize market opportunities (Hinrichsen et al., 2022; Walakira et al., 2023). As Africa's second-largest aquaculture producer, Nigeria has a high production rate in aquaculture and capture fisheries, but consumer demand still exceeds supply, making it one of the world's largest fish importers. Coastal areas have significant potential for mariculture, but industrial pressures, particularly from oil and gas, have hindered growth. Inland production leads in aquaculture output, yet scaling remains difficult due to limited land and insufficient incentives. Key challenges include limited access to affordable, quality feed ingredients and poorly developed infrastructure, which hampers feed distribution. The domestic supply of fingerlings also struggles to meet rising demand. Federal investment in aquaculture-specific legislation and a national strategy could boost production, reduce imports and enhance food security.

Mechanization

The private sector is key to mechanizing agriculture in Nigeria, but manufacturers and tractor owners need support through investments in transport, fuel, maintenance infrastructure and skill development programs (Daudu et al., 2022, 2020). Most tractors are sourced from private companies, though state-imported tractors still play a role. Private owners often provide hiring services, while those acquiring tractors through state programs are typically government employees with higher education levels. Challenges include limited capital, inadequate training, poor infrastructure, limited fuel access and a lack of maintenance services. Concerns about mechanization's potential negative impacts—such as soil erosion, youth unemployment and land-use conflicts—add to the barriers (Daum et al., 2020a). Supportive policies, including training programs to address knowledge gaps, are essential to enhance private sector participation in mechanization.

Renting tractors via digital technologies could accelerate mechanization in Nigeria, but challenges like seasonal demand, poor road and mobile infrastructure and low digital literacy must be addressed (Daum et al., 2021d). Digital platforms lower transaction costs for both providers and users, but issues such as mismatched supply and demand during peak seasons and delays caused by poor road networks persist. Tractors in Nigeria are mainly used for land preparation and transportation, with farmers typically accessing them through neighbors, relatives, or private companies. To improve access, the government has established Agricultural Equipment Hiring Enterprises and subsidized tractors for private entrepreneurs. New digital solutions like the Hello Tractor app are also emerging, enabling farmers to request tractor services remotely via smartphone or through agents. However, barriers such as limited internet connectivity, low smartphone usage, digital illiteracy and distrust in agents hinder their effectiveness.

Mechanization and automation technologies are widely used in Nigeria's food and beverage manufacturing sector. Training programmes are needed to close technical skill gaps and help employees adapt to changing technologies (Baumüller et al., 2023b). A survey among manufacturers shows all firms use machinery for processing and packaging and 55% also employ computer-controlled automation. Almost all of these machines are imported, primarily from Asia and Europe. Key benefits reported by the firms include improved product quality, greater efficiency, reduced costs and lower food waste. Most firms (79%) believe staff are qualified to operate these systems, though skill gaps in technical and computer skills are noted. Mechanization and automation have led to both job gains and losses (reported by about 34% of firms respectively). Job losses more frequently affected lower-skill workers. Around a third of workers —especially in automated firms— were reassigned to new tasks if needed. To support workers in adjusting to evolving technologies, targeted training to build technical skills is essential. Additionally, social safety nets should be in place to address potential job losses.

Nigeria's agricultural machinery sector is underdeveloped despite its market potential. Scaling it requires improved access to capital and raw materials, reliable electricity and road infrastructure and skilled labour will be essential (Daudu et al., 2022). A survey of machinery manufacturers reveals that most companies are privately and domestically owned. Company owners started their businesses for several reasons including encouragement by the family, participation in related courses or their personal aspirations. The companies produce machines mainly for crop production, post-harvest handling and processing, including threshing, shelling and milling. Larger equipment, such as tractors, is imported. Manufacturers face several challenges that must be addressed for the sector to thrive. Lack of capital was most frequently mentioned as barrier to entry. Other constraints include the high cost of raw materials, erratic power supply, inadequate training, insecurity, bad roads and insufficient commitment on the part of policymakers.

Digitalization

Nigeria's telecommunications infrastructure and digital agricultural services (DAS) remain underdeveloped, limiting their impact on farmers. Targeted policies and investments are needed to improve connectivity, business models and digital skills (Philip and Ndirpaya, 2020). While mobile phone access is widespread, reliable and affordable connectivity is hindered by high costs, regulatory hurdles, cable theft and erratic electricity. Despite hosting Africa's second-largest number of DAS, most remain small in scale. Preliminary evidence shows DAS can boost smallholder income and output, but more research is needed to link these gains to specific technologies. Mobile money adoption also remains low. For sustainable digitalization in agriculture, the private sector must lead, with government support to upgrade telecom infrastructure, including fiber networks and last-mile coverage. Training programs to enhance digital skills and scalable business models are crucial for the long-term success of D4AG in Nigeria.

The digital agricultural platform AgroMall demonstrates the potential impact of DAS on the functioning of agricultural markets (Philip and Philip, 2024). AgroMall connects farmers to buyers and provides services like

farming advice, weather updates, input access, digital payments and transport, leveraging digital technologies to improve supply chain management, data collection and advisory services. This has enhanced efficiency, transparency and inclusivity while reducing barriers such as poor infrastructure and high market margins. Key motivations include cost optimization, direct farmer-buyer interactions and facilitating finance access using precision farming for data-driven decisions. Despite successes, challenges remain, particularly for farmers without mobile phones, financial literacy, or land and a notable gender gap, as few registered farmers are women. Recommendations include policies to provide targeted support for female farmers and investments in rural infrastructure—such as transport and electricity—to improve connectivity and reduce transaction costs for all stakeholders.

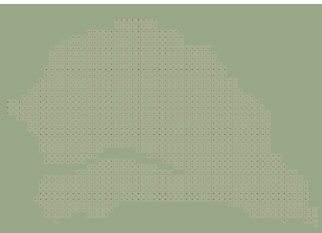
While adoption of DAS in Nigeria remains limited, digital technologies are widely used across the country's agricultural value chain. A survey of extension agents, input suppliers and output dealers found extensive use of digital tools in their work (Baumüller et al., 2023a). Mobile phones are the most commonly used tools, particularly smartphones which are used by 63% of respondents on average, in particular extension agents and input suppliers. Extension agents employ the widest range of digital technologies, utilizing diverse mobile phone functions to interact with a broad network of value chain actors and share a variety of information. Input and output dealers primarily use digital tools to reduce transaction costs and improve networking and information exchange. However, intermediaries still prefer face-to-face interactions for certain tasks, such as training and price discussions. Digital marketing platforms could capitalize on the digital skills and networks of intermediaries to improve service delivery and enhance access to smallholder farmers in remote areas.

Further up the value chain, digital technologies are widely adopted in Nigeria's agroprocessing sector, particularly through computer-controlled automation (see above). This demonstrates the transformative potential of digital technologies across the entire food and agriculture sector, extending beyond agricultural production.

Skill development

While students are generally satisfied with the quality of ATVET in Nigeria, further investments in practical training, digital skills, school facilities and female engagement are needed (Daudu et al., 2024). Nigeria's National Policy on Education includes a framework for agricultural vocational training. A survey of students shows nearly half of participants come from rural, farming backgrounds. Women are better represented in Nigeria's ATVET system than in other countries studied (Kenya, Benin, Mali), making up almost half of students and 30% of teachers. Most students aim to become agripreneurs, work in extension services, or join agricultural research organizations with only 11% aspiring to government jobs. Students praised the courses' relevance, qualified teachers and practical components but highlighted challenges, including inadequate facilities, limited internet and computer access and insufficient digital skills training. Addressing these gaps will require increased public investment.

3.11 SENEGAL



KEY TAKEAWAYS

Reducing post-harvest losses: Investments in cold chains and storage could cut Senegal's vegetable losses by 30%, boosting supply by USD 72 million annually and reducing imports by 22%.

Poultry sector growth: Senegal's poultry businesses thrive on vertical integration, protective trade policies and technical innovations, with producers diversifying operations and meeting peak demand through industrial-grade equipment.

Climate adaptation: Senegal's adaptation plans include income diversification and mitigation policies, but success requires participatory governance, secured funding and reliable data.

Employment: Agriculture could create rural jobs, especially for youth, but progress is slowed by limited financing, land disputes, and low mechanization. Policies must address these barriers.

Innovations in value chains

Investing in transportation, storage and conservation innovations could significantly reduce post-harvest losses, boost domestic vegetable supply and decrease Senegal's reliance on imports. Reducing on-farm vegetable losses by 30% could increase the annual value of vegetable supply by 45%, or USD 72 million, while cutting imports by 22% (127,000 tons annually) (Beye and Komarek, 2020). A critical step is establishing a cold chain between farms and markets, as the lack of cold or ventilated storage forces farmers to quickly sell or consume their produce, leading to losses. Effective storage and conservation technologies can substantially curb post-harvest losses. However, implementing these strategies will require careful financial planning, considering the costs to both farmers and the government.

Senegal's commercial poultry sector has grown rapidly over 15 years, driven by increased production, investments, and successful business models (Koki et al., 2022). One key model is integrated poultry farming, where producers operate under contract agreements with companies across the poultry value chain. Another involves diversification and reinvestment, with farms expanding into areas like vegetable gardening, tree farming, construction and telecommunications. Many farms have also benefited from customer loyalty, particularly from a few major buyers and adjusted production levels to meet demand during peak consumption periods. Technical innovations have been vital, with industrial equipment in Senegal matching standards in industrialized countries. Additionally, trade policies, such as the suspension of poultry imports, have given local producers a competitive edge, further boosting the sector's growth.

Climate change adaptation

Senegal employs household, community, and policy strategies to address climate shocks and land degradation, but challenges related to governance, funding and monitoring limit their effectiveness (Faye et al., 2021). Households have diversified incomes through remittances and non-agricultural activities, while communities have strengthened organizational dynamics to support vulnerable groups and improve access to climate information. At the policy level, Senegal has developed adaptation and mitigation plans to protect key sectors and reduce emissions. Effective implementation requires governance structures that enable participatory policy design to ensure stakeholder ownership. Securing funding, preferably from the national budget, is essential to align policy goals with realistic plans. Additionally, high-quality statistical data is critical for targeting interventions, optimizing resource allocation and evaluating progress, gaps and impacts.

Employment

Agriculture has significant potential to boost rural employment in Senegal, particularly for young people, if structural constraints in value chains are addressed (Mbaye et al., 2018). Organized value chains like rice benefit from state support, with farmers in the Senegal River Delta often able to produce rice year-round. Cotton cultivation also generates many direct jobs in production and ginning activities. However, progress is hindered by challenges such as limited access to financing, inadequate training, property rights disputes, low mechanization levels and insufficient access to affordable and efficient energy. To overcome these barriers, policy interventions should prioritize removing these obstacles and supporting small- and nano-enterprises, which are prevalent in rural areas, to create stable and sustainable employment opportunities.

3.12 TOGO

KEY TAKEAWAYS

Strengthen farmer organizations: **Togo's producer organizations enhance market access, technical skills and incomes. These initiatives help farmers secure better prices, boost productivity and improve nutrition through training and better association management.**

Boosting rice production: **While Togolese rice farmers widely adopt improved seeds, low use of modern practices and post-harvest technologies limits productivity. Addressing high costs, information gaps and climate risks is essential to enhance food security and encourage adoption.**

PARI team visit to the GIC in Togo

Selected value chains

The soya, cashew nut and groundnut value chains were initially selected for Togo's GIC (ZEF, FARA, and ITRA, 2017). **Soybeans** are increasingly popular among farmers and millers as a low-investment substitute for cotton. The crop has particularly benefited women by providing income through soya-based products like tofu. Private organizations are actively working to boost soybean production in Togo.

Cashew nuts are cultivated on a smaller scale, mainly in the central and eastern parts of the Plateau region, which account for 81% of producers. Revitalizing the cashew industry is gaining interest due to its potential for job creation in production, processing and marketing (ZEF, FARA, and ITRA, 2017).

Groundnuts are widely grown across the country, primarily by smallholder farmers and production nearly doubled between 2000 and 2014. The sector meets local demand through informal processing channels (Todjé et al., 2018a).

Innovations in value chains

Togo's service provider and producer organizations are effective channels for improving market access, technical knowledge and achieving better prices (ITRA et al., 2017). Notable examples include Soja Nyo, which supports soybean farmers and the Farmer Business School (FBS), which focuses on cashew producers. The FBS approach enhances farmers' entrepreneurial and business skills, educates them about market opportunities and offers strategies to improve productivity, family incomes and nutrition. It also provides practical guidance on cashew production and tools for managing farmer associations. Soja Nyo members have experienced increased incomes, improved nutrition and better market prices by storing produce until prices rise. This approach shows promise for disseminating technologies and expanding farmers' access to inputs.

The adoption of improved seeds is widespread among Togolese rice farmers, but the uptake of agricultural practices and post-harvest technologies remains low

(Todjé et al., 2018b, 2017). Several economic and institutional factors contribute to these low adoption rates, including high technology costs, information gaps and a lack of necessary equipment. These technologies are essential for boosting rice production, a crop critical to Togo's food security. However, the rice sector remains highly vulnerable to the impacts of climate change. To better support farmers, more impact assessments of these technologies in Togo's specific context are needed to guide decision-making and encourage adoption.

3.13 TUNISIA

KEY TAKEAWAYS

Political commitment: Tunisia's political prioritization has spurred advancements in durum wheat, organic olive oil and rapeseed production, reducing import reliance and increasing local demand, but support for conservation agriculture remains limited.

Livestock as climate strategy: Livestock supports climate resilience in Tunisia, but high costs and poor infrastructure limit productivity. Improved farmer training and youth engagement are essential.

Strengthening olive oil exports: Weak marketing, insufficient processing and lack of origin certification hinder Tunisia's olive oil sector. Investments in marketing and certifications can boost global competitiveness.

Solar milk cooling innovation: Solar-powered milk cooling extends milk freshness and reduces spoilage, enhancing quality from farm to market in Tunisia's dairy sector.

Youth in agriculture: To reduce rural unemployment, Tunisia must improve youth access to credit, training and digital tools, encouraging investment in agriculture.

Selected value chains

The milk and potato value chains were initially selected for Tunisia's GIC (INRAT et al., 2017). The **dairy** sector is a key contributor to the country's agriculture, accounting for 11% of total agricultural production value and about 25% of the livestock sector's value. Rising milk production is driven by changing diets and increasing purchasing power, providing an important coping strategy for producers while also creating valuable job opportunities in processing and marketing.

Potato production in Tunisia covers around 25,000 hectares across four cropping seasons. Despite growing local demand, only about 3% of potatoes are exported, leaving the country heavily reliant on imports to meet its needs.

The **milk** and **potato** value chains were selected for Tunisia's GIC. The dairy sector plays a significant

Innovations in value chains

Political commitment and engagement are crucial for the adoption of agricultural technologies in Tunisia (Zlaoui et al., 2018). Success stories include the widespread adoption of improved durum wheat varieties and the production of organic olive oil and rapeseed. These achievements have been driven by political efforts to prioritize these crops, such as reducing reliance on imported rapeseed to meet growing local demand. The private sector and agricultural engineers have also played significant roles in supporting these advancements. In contrast, technologies like meat product labeling and conservation agriculture have struggled to gain traction due to limited government support and insufficient financial resources. Despite its potential to restore ecosystem services and improve yields, conservation agriculture has not achieved the anticipated success (Souissi et al., 2018).

In Tunisia, livestock is increasingly viewed as a coping strategy for climate change, yet the adoption of technologies to enhance productivity remains low (Bedhiaf et al., 2018; Dhraief et al., 2018). Livestock contributes 4% to Tunisia's GDP and 41% of total agricultural production. The sector benefits from the availability of barley and cactus for feed—barley-based systems are profitable and spineless cactus serves as valuable fodder during dry seasons. While the sector is steadily growing, it faces challenges such as high production costs, forage shortages, inadequate infrastructure and limited access to information (INRAT et al., 2017). Policies should prioritize improving farmers' knowledge of agricultural technologies to enhance livestock productivity, with a focus on actively engaging young people.

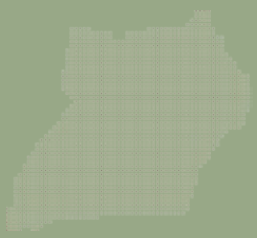
In Tunisia's dairy value chain, value addition efforts have focused on improving fodder to enhance the quality of meat and milk (INRAT et al., 2017). To extend the shelf life and quality of milk, a cost-effective solar-based milk cooling system has been promoted among farmers (Salvatierra Rojas et al., 2018). Developed by the University of Hohenheim, this system uses conventional milk cans and ice produced in a solar-powered freezer. The ice allows milk to stay fresh for six to sixteen hours, depending on the amount used. This innovation ensures year-round ice production, helping farmers maintain milk quality from the farm to collection centers or markets.

Tunisia, a leading olive oil producer and the largest olive grower in the southern Mediterranean, faces challenges like weak marketing, lack of origin certification, and limited processing facilities (Zlaoui et al., 2019). Tunisia's olive oil struggles to gain international recognition due to the absence of coordinated marketing efforts, a system for designating origin and low awareness of its quality in global markets. Additionally, the sector suffers from a shortage of processing units. Introducing certificates of origin and increasing investment in marketing and commercial activities could enhance Tunisia's competitiveness and strengthen its position in the global olive oil market.

Employment

Access to credit and loans is crucial to encouraging young Tunisians to invest in agriculture, creating employment opportunities in rural areas (Zlaoui et al., 2022). Low youth engagement in agriculture is driven by challenges such as limited access to land, credit and markets. Rural unemployment rates are higher than the national average, partly due to insufficient investment in innovations that could boost productivity. To attract young people to agriculture and encourage them to remain in rural areas, targeted incentives are needed. These include improved access to credit and financing for entrepreneurs, better extension services, training and coaching programs and enhanced digital services to support agricultural activities.

3.14 UGANDA



KEY TAKEAWAYS

Strengthen seed systems: Decentralizing seed services in Uganda has boosted quality seed access through growing community seed banks and local seed businesses, though financing remains a challenge.

Boosting fertilizer use: Fertilizer adoption is low due to high costs, poor regulation and limited government support. Addressing these barriers requires subsidies and better infrastructure.

Easing women's workload: Women in Uganda bear a heavy unpaid labour burden, limiting economic opportunities. Access to education, mechanized tools, childcare and better infrastructure—like water and electricity—can ease workloads, boost productivity and improve well-being.

Seed systems

Decentralizing seed services in Uganda has significantly improved farmers' access to quality seeds (Waithaka et al., 2021). Between 2016 and 2021, the number of community seed banks (CSBs) grew from one to five, while local seed businesses (LSBs) expanded from 27 in 2012 to 256 by 2020. Enhanced collaboration among stakeholders has been key to strengthening seed production. LSBs have formed strong partnerships with the Zonal Agricultural Research and Development Institute (ZARDI), while CSBs work closely with the Plant Genetic Resources Centre. The Integrated Seed Sector Development (ISSD) agency coordinates efforts to promote Quality Declared Seed (QDS) production across the country. However, financing remains a major barrier to further decentralizing seed production, limiting the potential for greater impact.

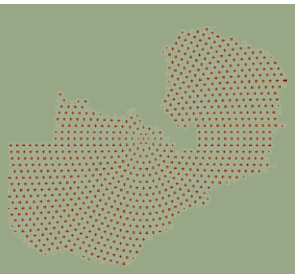
Fertilizer production

Supply-side challenges, such as quality control, subsidies and transport infrastructure, are key factors affecting mineral fertilizer uptake in Uganda (Olaleye and Edje, 2020). Fertilizer application remains low, averaging just 2 kg per hectare, far below the sub-Saharan African average. Fertilizer supply has been driven primarily by cash crops like tea, sugar and oil palm, while smallholder farmers have been largely neglected. Government involvement has been limited to regulations and advisory services, with no fertilizer subsidies for smallholders since the 1990s. This lack of support has led to poor quality control, including improper labeling and frequent adulteration of fertilizers. NGOs have stepped in to import and distribute fertilizers, but total imports remain low—40,000 tonnes in Uganda compared to 480,000 tonnes in Kenya in 2010. High transportation costs, the second-largest fertilizer expense, further hinder adoption. To increase fertilizer use, Uganda needs stronger market regulation, transportation subsidies and investments in infrastructure improvements.

Women empowerment

Gender disparities in labour division persist in Uganda, with women bearing a disproportionate burden of unpaid work. A fairer task distribution and technological innovations are essential to reduce this workload (Isoto et al., 2024). Women spend more time on total work, especially unpaid tasks, though their participation in paid work increases with higher education, underscoring the need for improved access to education and vocational training. Access to agricultural technologies affects time allocation, boosting men's paid work and reducing women's unpaid tasks. For low-income women, shorter distances to water sources decrease unpaid work and increase paid work. Women's time in both work types correlates with improved children's dietary diversity, highlighting the importance of investments in amenities like piped water, electricity and transportation infrastructure. Expanding access to mechanized agricultural tools can ease women's manual labour burden, particularly those with limited education, for whom paid work often hinges on available opportunities. High-quality childcare facilities and a more equal distribution of care work are also needed to free up women's time and improve their well-being.

3.15 ZAMBIA



KEY TAKEAWAYS

Scaling agricultural innovations: Platforms promoting soybeans and fortified maize in Zambia have increased adoption of improved seeds, training and market access, helping combat vitamin A deficiency and benefiting women farmers.

Farmer innovations: Zambian farmers develop cost-effective innovations to improve productivity but need support for validation, commercialization and greater involvement of women.

Herbicide impacts: Herbicides boost yields but may reduce edible weeds vital for nutrition and resilience. Policies should balance productivity with food security.

Mechanization: Private initiatives, like John Deere partnerships, have increased incomes and food security. Training on maintenance and sustainable practices is needed to address environmental concerns.

Youth and farming: Zambian youth see farming as viable with supportive policies. Programs must align with actual aspirations of rural youth to avoid misguided policies.

Selected value chains

The soya, groundnut and milk value chains were initially selected for Zambia's GIC (ZARI et al., 2017). **Soya** is produced on a large scale, mainly for export, with some meeting local demand. Growth in the sector is driven by the expansion of cultivated areas rather than yield improvements. There is significant potential to increase soybean production, particularly as feedstock for poultry farming.

Groundnuts, in contrast, are produced on a small scale, primarily for home consumption, accounting for about 9% of the total harvested area. Local demand is heavily supplemented by imports.

The **milk** sector includes both commercial and traditional cattle farmers, with traditional farmers often relying on their cattle as a coping strategy during crises. Most milk is sold through informal channels. However, the sector faces challenges such as shortages of raw milk for processing, increasing reliance on cheaper, lower-quality milk imports.

Innovations in value chains

Innovation platforms have proven effective in promoting agricultural innovations, particularly for the adoption of soybeans and fortified maize (Chomba et al., 2018, 2016). These platforms bring together key stakeholders along value chains to address challenges and opportunities related to specific commodities. A notable example is the promotion of fortified maize. In 2010, the government established the National Pro-Vitamin A Orange Maize Steering Committee (NPASC) as an innovation platform, enabling the development of fortified orange maize varieties. This effort was a collaboration among HarvestPlus, the International Maize and Wheat Improvement Programme (CIMMYT) and the Zambia Agricultural Research Institute (ZARI). Orange maize is included in the government's agricultural input subsidy program, helping to address vitamin A deficiency among pregnant and lactating women as well as children under five.

Farmer innovations

Zambian farmers are active innovators to address constraints in agricultural production, but measures to validate their innovations, assist with commercialization and empower women innovators are needed (Tambo, 2018). A farmer innovation contest implemented by PARI in the country yielded an impressive range of innovations, mostly in the areas of livestock production and to a less extent crop management and storage. Most of the innovations (68%) added value to or adapted technologies and practices to make them more appropriate to local conditions while the rest were original innovations. The innovators were mainly motivated by the desire to increase agricultural production and reduce production costs, which they also see as the main benefits of their innovations along with the increase in knowledge. Farmers mostly invested only limited financial resources (USD 20 or less) in the development. While around 53% were aware of others who had adopted their innovation, more support is needed to help interested innovators to validate their innovations and convert innovations with commercial potential into marketable products. Also, women were underrepresented in the contest, accounting for only 24% of innovations. More efforts need to be made to encourage women to innovate and to showcase their innovations.

Herbicides

Edible weeds play a significant role in the diets of rural households in Zambia, especially during the lean season. However, the use of herbicides, while often associated with increased crop yields, may threaten the availability of these important food sources (Daum et al., 2021b). Currently, the adoption of herbicides among farmers in rural Zambia is low, so the impact on the consumption of edible weeds is not yet clear. However, households that have been using herbicides for an extended period tend to consume fewer edible weeds. These weeds are vital for nutrition, as they provide essential calories and nutrients. For example, Amaranthus hybridus is rich in vitamin A, iron, zinc and protein, while Bidens pilosa is a good source of iron. The relatively higher consumption of edible weeds in the Southern Province compared to other regions may reflect a coping strategy during prolonged droughts. This highlights how edible weeds contribute not only to food security but also to household resilience. Therefore, policies that promote the use of herbicides should carefully consider the potential trade-offs related to food and nutrition security.

Mechanization

Private sector-led initiatives are playing a key role in advancing mechanization in Zambia, particularly for medium-sized farmers (Adu-Baffour et al., 2019; Heni et al., 2020). Farmers partnering with John Deere have doubled their incomes by cultivating more land, improving their children's education and enhancing food security. Contrary to concerns that mechanization reduces rural employment, increased machinery use in Zambia has raised demand for labour due to land expansion and the reallocation of family labour. John Deere supports mechanization by offering credit or loans for tractor purchases and providing post-sale maintenance services. The company has also partnered with two NGOs to improve farmers' access to tractors. While this model shows promise for scaling mechanization, awareness of potential environmental impacts from land expansion is crucial. Extension services should be provided to educate farmers on soil fertility management to ensure sustainable practices and environmental conservation.

Improving farmers' knowledge and skills in tractor maintenance can significantly reduce breakdowns and associated costs (Thoelen and Daum, 2019). In rural Zambia, limited access to information and repair services leaves farmers with insufficient capacity to maintain tractors. Farmers need basic knowledge of key systems such as the engine, fuel, lubrication, hydraulics and electricity, along with agronomic skills like adjusting ploughing depths for conservation agriculture and soil fertility improvement. Hands-on vocational training programs could provide an effective solution by offering short-term, practical training to equip farmers with these essential maintenance and operational skills.

Gender differences in land preparation are more pronounced in households using tractors compared to those relying on manual labour, though it is unclear whether women's involvement in land preparation signifies empowerment or disempowerment (Daum et al., 2021a). Mechanization can still empower women by freeing up their time for off-farm work while men take on childcare responsibilities (Daum and Birner, 2019). Tractor use enables households to cultivate more land and reduces labour-intensive tasks like weeding. However, men tend to perform the more physically demanding tasks that require greater energy. Policies promoting mechanization should address these gender dynamics and consider the energy demands of different agricultural tasks to tackle undernutrition and malnutrition among smallholder farmers.

Youth aspirations

Rural youth in Zambia have diverse opinions and aspirations, carefully weighing the positives and negatives of farming, rural and urban life and even foreign countries (Daum, 2019). Rather than speaking with one voice, young people express multiple perspectives, with even single respondents articulating varied views. Many expressed interest in farming, pride in being self-sustaining and enjoyment in living in their villages, indicating that rural areas can be attractive with the right policies. When imagining their future farms, most young people envisioned using draught animals, having electricity, diversifying their farms and applying more fertilizer. However, few mentioned modern technologies like tractors and none referenced digital. These findings highlight the need for policymakers and development practitioners to align programs with the actual aspirations of rural youth to avoid well-meaning but misguided policies.

Parents play a key role in shaping their children's career aspirations, particularly in rural areas, where traditional gender norms heavily influence these aspirations (Ogunjimi et al., 2023). Young men are often encouraged to pursue farming, while young women are discouraged, reflecting a patriarchal system. This bias is reinforced by the practice of allocating farmland to sons, fostering ambitions for larger commercial farms among young men. In traditional societies where parents hold significant influence, understanding these dynamics is essential. Young people's satisfaction with farming is closely linked to their parents' attitudes toward it. This underscores the importance of incorporating parents' perspectives into policies and programs aimed at rural youth.

Interview with a tractor owner in Zambia

4 POLICY ENGAGEMENT AND POLICY IMPLICATIONS

4.1 INNOVATIVE POLICY ENGAGEMENT OF PARI AND ITS NETWORK

From its inception, PARI has sought to inform policy processes through evidence-based recommendations. Over the past decade, it has played a key role in transforming the conceptual framework for food and agricultural development, shifting from a value chain perspective to a more comprehensive food systems approach in German, African and international policy fora. PARI has actively engaged in policy processes by publishing nearly 40 policy briefs, organizing close to 50 events at national, regional and international levels and disseminating its findings through social media, conferences, bilateral policy engagements and its website. Some highlights include:

- PARI offered input into the **strategic direction of the SEWOH** by regularly synthesising relevant PARI insights into strategy documents for the BMZ and actively participating in the Advisory Group of the SEWOH.
- PARI contributed to shaping discussions in the lead-up to and at the **UN Food Systems Summit (UNFSS) 2021** by co-facilitating the formulation of an "African Voice" for the UNFSS (FARA et al., 2021) and feeding research insights into the work of the UNFSS Scientific Group chaired by PARI Director Professor Joachim von Braun, the UNFSS Science Days on 5-7 July 2021 (see https://sc-fss2021.org/events/sciencedays) and the collection of research chapters on "Science and Innovations for Food Systems Transformation" edited by Joachim von Braun and the co-chairs of the UNFSS Scientific Group (von Braun et al., 2023).
- PARI engaged in the **T20/G20 processes** led by India (2022) and Brazil (2023) by co-authoring strategic T20/G20 policy briefs and as a member of Brazil's Task Force 1: "Fighting inequalities, poverty and hunger" represented through Joachim von Braun.
- PARI synthesised key findings from PARI research and recent state-of-the art literature in a **book to identify investment and policy priorities on how Africa may secure its supply of food for affordable and healthy diets from the sustainable use of its resources** (Baumüller et al., 2020). The study was presented to BMZ and African partners and widely circulated among key policy stakeholders in Africa.
- PARI regularly organized sessions at the annual **Africa Food Systems Forum (formerly African Green Revolution Forum)**, which brings together leading policy stakeholders engaged in African food and agriculture, to share PARI research findings and discuss related policy implications.
- PARI research informed the policy reports published bi-annually by the **Malabo-Montpellier Forum**, is a group of international agriculture experts who guide policy choices that accelerate progress towards food security and improved nutrition in Africa co-chaired by Joachim von Braun and PARI partner Ousmane Badiane from AKADEMIYA2063 (available at https://www.mamopanel.org).
- PARI facilitated **research and exchanges among African and Indian food systems actors** by organising a study visit of agricultural researchers to India (2017), conducting comparative studies on issues of policy relevance to both regions (as summarized above) and presenting the resulting findings at India-Africa seminars (2021, 2024).
- PARI had a focus on farmers, women and youth in Africa throughout. PARI also gathered African youth studying and working in Germany at a **Youth Townhall Meeting with entrepreneur Strive Masiyiwa** at Humboldt University in Berlin on 3 December 2018 to discuss how innovation and entrepreneurship can drive food security and jobs in Africa.

PARI in itself represents an innovative approach to development investments by integrating independent accompanying research as a complementary and alternative element to the traditional cycle of program planning, investment, monitoring and evaluation. The PARI approach offers three important advantages: First, it facilitates program-embedded, evidence-based, two-way learning among partners. Second, it can quickly incorporate emerging research insights from programs operating in diverse contexts. Third, it has the potential to lower the overhead costs of development programs. However, for this approach to succeed, development management and investment communities must build trust in partnerships and in research. As research capacities in emerging economies continue to grow, partnerships like those fostered by PARI between Germany, Africa and India have significant potential to drive innovation in development cooperation and program management in the future. An external evaluation of PARI further validated its effectiveness, highlighting positive findings and offering strategic recommendations that can guide the design of future PARI-type programs, even beyond the food systems context (Admassie, 2024).

Field visit of African PARI researchers to India

4.2 POLICY IMPLICATIONS

A number of key insights and recommendations emerged from the research that can shape policies that support the transformation of Africa's food systems:

- **Promote context-specific innovation packages for productivity growth**

  Boosting the productivity of African agriculture will require locally adapted innovation packages that combine multiple innovations for maximum impact. Key priorities include improving access to high-quality seeds, promoting irrigation and enhancing the availability of inputs for the livestock and aquaculture sectors. Balancing sustainability trade-offs is crucial to ensure economic, social and environmental goals are achieved. Specific recommendation include:

  Improve seed systems: Decentralized seed systems, long-term funding and better dissemination of varietal information are critical to increasing the adoption of improved seeds among small-scale producers.

  Promote small-scale irrigation: Investments in locally adapted small-scale irrigation technologies must address water scarcity and promote sustainable water management, while integrating irrigation with other yield-enhancing measures like improved seeds and fertilizer.

  Expand animal-based production: Strengthening Africa's livestock and aquaculture sectors requires investments in affordable feed and breeds, private-sector engagement, market linkages and tailored policies that balance sustainability trade-offs.

  Foster sustainable production: The adoption of agroecological practices, in particular combining organic and mineral fertilizers, can enhance land productivity in African smallholder farming, but their effectiveness depends on local conditions and specific practices Comprehensive PARI research shows that closing yield gaps remains challenging for agroecological practices.

- **Recognize and scale farmer innovations**

  Farmers are a valuable source of scalable and effective innovations. Many independently develop locally adapted solutions to challenges like pest control and livestock health, improving food security, incomes and reducing costs. To scale these innovations, they need recognition and integration into research systems, along with support for documentation, validation and commercialization.

- **Scale locally adapted mechanization**

  Mechanization and digitalization present significant opportunities to modernize African agricultural production and processing. Mechanization can boost productivity, generate income and increase product quality. The adoption of digital technologies, in turn, has the potential to significantly increase land and labour productivity in agriculture and enhance value chain efficiency. Specific recommendations include:

  Promote mechanization of production: Expanding mechanization in agricultural production in Africa depends on affordable, locally tailored machinery and investments in financing, skills, infrastructure and sustainability.

  Invest in modernization of agroprocessing: Scaling the adoption of mechanization and automation in processing requires investments in power infrastructure, access to machines and spare parts, as well as skilled workers to operate and maintain advanced technologies.

  Growing local manufacturing: Investments in financing, skills, infrastructure and regulations are crucial to unlock the full potential of local machinery manufacturing in Africa.

- **Accelerate digitalization in food and agriculture**

  Digital technologies could transform African agriculture by boosting productivity and market access. However, despite widespread mobile phone use, the adoption of digital agricultural services remains limited due to challenges such as low digital skills, inadequate infrastructure, high costs, policy barriers and systemic agricultural issues. Specific recommendations include:

  Invest in digital skills and infrastructure: Expanding access to affordable technologies and connectivity and providing digital training for agricultural stakeholders will ensure more equitable benefits from digital technologies across agricultural value chains.

  Enhance access to integrated platforms: Foster the adoption of digital agricultural services by consolidating services into user-friendly platforms that accommodate varying skill levels and leverage intermediaries to connect smallholder farmers.

  Improve data protection: Strengthening data privacy laws, enforcement mechanisms and farmer awareness is crucial as digital services collect increasing amounts of agricultural data.

- **Connect producers to markets**

  Improving market access for small-scale producers in Africa requires strengthening domestic and intra-African market linkages, investing in infrastructure like cold chains, storage and transport and fostering farmer associations and public-private partnerships. These measures can improve value chain efficiency, increase competitiveness and incentivise productivity-enhancing investments.

- **Harness the employment potential of the food sector**

  Creating jobs for Africa's youth will be a major challenge in the years ahead. Increasing agricultural productivity and sales can generate income for producers, while the agroprocessing sector offers substantial potential for job creation. To capitalize on these opportunities, it is essential to invest in ongoing workforce development,

focusing on building the knowledge and skills needed for modern agriculture and agro-industrial growth. Specific recommendations include:

Expand agricultural extension services: Extension services should be designed so as to harness their proven potential to boost the adoption of farming technologies (in particular fertilizer and improved seeds) and improve food security.

Reform vocational training: To improve the efficiency of vocational training, investments in digital technologies, upgraded facilities and practical training are essential to prepare youth for modern agriculture.

Enhance sustainability in training: Agricultural education in Africa needs stronger integration of sustainability topics. Barriers like limited materials and weak stakeholder connections must be addressed to enhance impact.

- **Strengthen the voice and economic empowerment of women**

  Women face structural barriers and restrictive social norms that limit their participation in economic activities and decision-making. Their heavy burdens of both paid and unpaid work negatively impact their well-being and that of their families. Enhancing women's access to land, technologies, education, finance, childcare support and fair wages is essential to enhancing their equality, productivity and income within Africa's food systems.

- **Enhance innovation systems**

  Both the development and scaling of innovations will require a stronger innovation ecosystem, with improved access to finance, raw materials, market links and innovation hubs. Related investments and activities need to be designed for the long term because sustainable innovations based on science take time to be impactful. Infrastructure gaps remain a major concern. Tailored investment plans that address local conditions and combine infrastructure elements—such as roads, electricity and water—can maximize employment and economic benefits.

- **Foster India-Africa learning**

  Since 2000, Africa and India have experienced significant agricultural growth, which has contributed to improved nutrition and health. However, despite these advancements, both regions continue to struggle with high levels of food insecurity. Given their similar agricultural contexts, there is substantial potential for these regions to learn from one another. Examples include:

  Scaling bottom-up innovations: Farmers in both regions are actively developing solutions to address agricultural challenges. India's Honey Bee Network provides a valuable model for Africa to recognize, document and commercialize grassroots innovations, turning local ingenuity into scalable solutions.

  Mechanization in smallholder production systems: While India has higher tractor usage and a robust manufacturing sector that exports to Africa, smallholders in both regions face challenges accessing machinery. Expanding tractor hire services, already present in both regions, could improve affordability and accessibility for small-scale farmers.

  Commercialization of poultry production: Poultry serves as an essential source of income and nutrition in India and Africa. The private sector has driven success through vertical integration, e.g. through contract farming in India and value chain diversification within companies in Senegal.

PARI Youth Townhall with Strive Masiyiwa in Berlin

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