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SUSTAINABLE FOOD SYSTEMS FOR FOOD SECURITY

Need for combination of local and global approaches

A. Thomas, A. Alpha, A. Barczak, N. Zakhia-Rozis, editors

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Sustainable food systems for food security

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Alban Thomas, Arlène Alpha, Aleksandra Barczak, Nadine Zakhia-Rozis, editors

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Foreword

Food systems, understood as all activities and actors connecting food production, transportation and storage, processing and catering, distribution, preparation, consumption, and waste and resource management, as well as agricultural input suppliers and the associated regulatory institutions, represent a huge share of human activities and livelihoods. They are also at the centre of humanity's main challenges: climate change, human and environmental health, biodiversity erosion, equitable human development and, naturally, food and nutrition security.

Food and nutrition security is therefore a major area of research in food, agriculture and the environment. Achieving global food security involves identifying ways to transform our food systems to provide sustainable, healthy and accessible food to all human beings, who will number nearly 10 billion by around 2050. New paths forward should encompass all dimensions of food security: availability of agricultural and food products, access to and utilization of food, and stability in the food supply. Designing and accompanying agricultural and food system transitions and achieving global food security covers an incredibly large set of issues, scientific disciplines and scales of analysis. It is therefore not surprising that CIRAD and INRAE, France's two main agricultural research institutions, have taken up a joint research programme on food security. GloFoodS (Transitions for Global Food Security) was launched in 2014 as a 'metaprogramme', an INRAE initiative to address a specific challenge with an interdisciplinary perspective, a dedicated budget and a roadmap shared by stakeholders. But what truly made GloFoodS original was the idea of developing a metaprogramme as a joint CIRAD-INRAE initiative for the first time and bringing together the multidisciplinary scientific skills of INRAE (then INRA) and CIRAD to explore the four dimensions of food security, while also incorporating the public policy dimension.

The GloFoodS flagship programme (2014 to 2020) was a unique experience in joint research management for CIRAD and INRAE. It was motivated by the strategic importance of food security as a research subject in our strategic plans, as well as by the need to gain visibility in international forums on global issues involving food security governance. Beyond the rather conventional analysis of the balance between agricultural supply and food demand, along with the role of food security governance models, GloFoodS added five more areas of research: trends and variability in crop and animal yields; production potential of additional land; innovations in products, processes and organizational approaches to limit food waste; determinants of nutritional transitions and their health and environmental impacts; and links between household access to food and poverty.

When the metaprogramme came to a close at the end of 2020, the scientific leaders behind GloFoodS proposed a series of outreach events, including a final programme workshop. They also formed a scientific committee to edit a volume of contributed chapters from research findings obtained with the support of the GloFoodS programme. As readers can see from the list of chapters, the wide range of topics and scientific fields and disciplines is consistent with the scope of our initial objective when GloFoodS was launched by our two institutions. The metaprogramme covered a variety of areas and challenges, ranging from food security governance to the impact of food and nutrition transitions on agricultural systems and practices, the global balance between food production and availability, the challenge of reducing food waste by optimizing food processes, the drivers of the agroecological transition in developing and industrial countries, and the relationships between food security, access to land and natural resources at the local level.

By enhancing the joint provision of scientific knowledge on issues related to food security by CIRAD and INRAE, GloFoodS has also contributed to strengthening the position of our research institutions in public debates and international initiatives on food security. It is clear that global food security will remain on the CIRAD and INRAE research agenda for some time, as demonstrated by our priorities and objectives (INRAE 2030 Roadmap, CIRAD Scientific and partnership strategy 2019–2023).

For INRAE, this is particularly true for one of its five scientific priorities detailed in the INRAE 2030 strategic document ('INRAE2030 – Building a sustainable future through shared science and innovation'): 'Accelerating agroecological and food transitions while answering socioeconomic challenges'. Within this general priority, a first proposal is to strengthen our understanding of transition processes and food security challenges, such as by modelling and evaluating foresight scenarios of changes in food supply and demand at the global scale; analysing the variety of food systems with regard to their autonomy and resilience at various scales; and analysing trends in agricultural structures and factors of production, including land and labour, their autonomy with respect to public support policies and their vulnerability to global risks (climate, markets, etc.). A second proposal concerns the design of healthy and sustainable food systems available to all. Examples of specific objectives include a more comprehensive understanding of the factors of changes in food systems at the global and local scales, and the evaluation of the health, economic, social and environmental impacts of such changes.

For CIRAD, which works specifically on food systems in developing countries, four out of six of the key thematic fields in its 'Scientific partnership and strategy objectives' (OSSP2 covering the period 2019–2024) are directly linked to food systems and GloFoodS research questions: engineering the agro-ecological transition, using territories as levers for sustainable and inclusive development, supporting the transition to more sustainable and inclusive food systems; and helping farming systems in the Global South adapt to climate change. CIRAD is convinced that food systems must change to be able to produce more and better, address all agroecological principles, and ultimately improve food security, the core component of the development-health-climate-environment nexus.

The upcoming United Nations Food Systems Summit (UNFSS) is a strong call to action where leaders expects bold moves and disruptive decisions. The world's scientific communities must mobilize. Our research institutions have a duty to produce scientific knowledge for which international partnerships are essential, issue guidance for decision-makers, and ultimately bring about real change. We hope readers of the English version of this book (the French version is forthcoming) will be interested in learning more about the scientific communities at CIRAD and INRAE that work on the numerous dimensions of food security and will gain new insights on the topic of food security.

Michel Eddi, former CEO of CIRAD and Philippe Mauguin, CEO of INRAE

Preface

Food and nutritional security refers to the challenge of providing sustainable, healthy and accessible food to all human beings. It comprises four dimensions covering overlapping issues: availability, utilization, accessibility and stability. This tremendous challenge requires a transformation of the world's food systems and the mobilization of all stakeholders and policymakers based on knowledge and scientific evidence. There is a clear need for intersectoral and more integrated knowledge, which is why two major French agricultural research organizations, CIRAD and INRA (which became INRAE in 2020), led an ambitious interdisciplinary flagship programme between 2014 and 2020 on the transitions for global food security: the GloFoodS metaprogramme. This metaprogramme called upon the multidisciplinary scientific skills and the international experience of both institutions to explore the balance and discrepancies between agricultural supply and food needs and the role of governance modes of food security, while accounting for the potential impact of global change. It operated on a variety of scales, from the global level all the way down to the household level. It funded 45 research projects (involving 35 PhD doctoral students) over the 2014–2020 period, mostly with international academic partners and often with stakeholder participation in more than 25 countries, covering a wide range of topics informing food and nutrition security in response to four overarching questions: 1) How does the evolution of agricultural production affect households' dietary transitions and access to food? 2) How does the evolution of agricultural production interact with the efficiency and sustainability of food systems, especially losses and waste? 3) How does governance affect agricultural production systems and land use? 4) How do dietary transitions affect the balance of food availability, agricultural production systems and land use?

The GloFoodS metaprogramme contributed to international research on food security with regard to several dimensions. First, it combined original approaches in agronomy, environmental sciences, nutrition, economics and sociology, among other disciplines, while also adopting a global viewpoint. Second, it connected global change components (climate change and global change, management of natural resources) with nutritional transitions of populations and the impact of those transitions on agrifood chains. Such a global positioning was naturally combined with local approaches so as to compare regional outcomes of global scenarios with observations at a smaller geographical scale. The GloFoodS metaprogramme therefore addressed questions related to agricultural sciences, livestock systems, global modelling, land-use changes, economic and sociological patterns in rural areas, agrifood technologies, nutrition and food security governance. Finally, GloFoodS aimed to provide original research at the interface of food security challenges that are often highly specialized in terms of fields and disciplines.

This book proposes a selection of results that draw upon research projects funded by GloFoodS. The findings address the issue of governance of food systems, the links between agricultural supply and food and nutritional needs, agroecological innovations and dietary diversity, the challenges of innovative processing of high-quality foods, agroecology and resilient food value chains, and local resource management as a driver of food security.

Conducting the GloFoodS metaprogramme over this period was a formidable scientific and human challenge for us and for the scientific community involved at CIRAD and INRAE. We hope that this book will be useful to readers interested in transitions towards global food security, and that the enthusiasm with which we accompanied the participating researchers will be reflected throughout its pages.

Alban Thomas, INRAE, and Etienne Hainzelin, CIRAD,
co-directors of GloFoodS

Introduction

Alban Thomas, Arlène Alpha, Aleksandra Barczak,
Nadine Zakhia-Rozis

World food security is consistently associated with the challenge of providing sustainable, healthy and accessible food to all human beings, whose total population is expected to reach between nine and ten billion around the year 2050. The definition of food security adopted at the World Food Summit in 1996 was the following: 'Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life'. From this definition, as well as its shorter version ('adequate access to food for all people at all times for an active, healthy life'), four dimensions of food security are generally accepted: availability, accessibility, utilization and stability. These dimensions encompass specific or overlapping issues.

First, availability of food depends on the capability of the world's food systems to produce food at the necessary quantity and quality demanded. The second dimension concerns access to food and is related to the issues of poverty and social inequalities that limit access to a balanced diet for a large part of world's population. Third, final food consumption addresses the issue of ongoing diet transitions, the consequences of under- and overnutrition and the resulting double burden. Fourth, most stages of food systems (crops and livestock, agrifood chain, retail, etc.) must deal with volatility and risk in markets and in the supply chain, resulting in instability of market prices. Moreover, each of these four dimensions is impacted by global changes that are already at play, especially climate change but also the depletion or degradation of natural resources and demographic and energy transitions.

Food security becomes even more complex when it comes to the scale of analysis, the type of actors involved in food systems and the geographical areas studied. More precisely, the concept is pertinent at the global scale (how do we feed the world in the coming decades?) and the local scale (how do we design more sustainable food systems at the community level?), as well as for various settings (urban food systems and the management of urban solid waste, sustainable livelihoods in rural areas). Having access to a sufficient quantity of healthy food is of course a major concern in developing countries, but it is also an issue for vulnerable population segments in developed countries. On the producer side, improving agricultural cropping and livestock systems is also relevant for a wide range of geographical regions, to make them less detrimental to the environment and ensure they do not jeopardize the availability of natural resources for future generations.

From the brief exposition above of the formidable challenges implied by the food security objective and its implications for food system organization and performance in their agricultural production, food processing, distribution and final consumption stages, it is clear that food security requires a significant interdisciplinary drive.

This book presents a collection of chapters authored by researchers from CIRAD and INRAE, who were principal investigators or contributors to research projects funded by the GloFoodS metaprogramme from 2014 to 2020. While these chapters do not form an exhaustive list of all topics, approaches, or global or regional challenges of food security, they are nevertheless representative of interdisciplinary research conducted with the support of GloFoodS. Compared with other published collective contributions on food security, this book presents research results corresponding to, in our view, a wider scope of disciplines and dimensions of food security, while providing recent research results. Another source of originality lies in the variety of scales of analysis as well as in the combination of local and global approaches to food security.

The book is divided into six sections of two to three chapters each. The first section addresses the issue of food system governance.

Chapter 1 by Arlène Alpha, Antoine Bernard de Raymond, Sandrine Fréguin-Gresh and Allison Loconto uses food security governance as an analytical framework to show that the governing effects of food security discourse might be more pervasive than structured debates and formal policies. The authors illustrate the operationality of their governance analytical framework to reveal the consequences of framing food security in a particular way and applying instruments that put those frames into practice through three case studies: a national food programme in Nicaragua, the resilience agenda and its operationalization in the Sahel, and land-use modelling. These case studies provide a convincing argument for the usefulness of such approaches in analysing food security where ostensibly neutral instruments have the power to constrain the possibilities for action, which in turn shape actors' behaviours.

Chapter 2 by Céline Bignebat, Romain Melot, Paule Moustier, Emmanuel Raynaud and Guillaume Soullier explores the governance of land and food value chains and its impact on populations' livelihoods. They acknowledge that the literature increasingly accounts for the role of farmers' livelihoods in fostering food security, including access to land and markets, public policies, the actions of private macro-stakeholders in land transactions and the trade of agricultural products, as well as land governance associated with value chain governance. Case studies combine territorial governance with value chain governance through agribusinesses (Senegal), analyse the development of an industrial zone driven by public investors (Morocco) and detail local levers for the regulation of land use (France).

The second section concerns the links between agricultural supply and food and nutritional needs.

Chapter 3 by Sophie Drogué, Sandrine Costa, Michel Simioni, Viola Lamani, Marie-Josèphe Amiot and Caroline Méjean addresses the nutrition transition through food supply and demand using cross-perspective approaches in economics, management and nutrition. The authors consider different contexts of nutrition transition to explore global changes (including the dynamics of available food supply and urbanization) and societal changes that generate dietary shifts. This chapter also studies some of the levers to curb nutrition transition centred on the perceptions and beliefs of consumers and their socioeconomic status. The first case study looks at the nutritional quality of food imports to the French West Indies, with the identification of socio-economic determinants of food demand, in a context where food supply is highly dependent on imports. The second case study is about socio-demographic determinants of nutrition transition in Vietnam, taking into account the changes in consumer behaviours and eating habits within the studied population.

Chapter 4 by David Makowski, Rotem Zelingher and Christophe Gouel explores the origins of shocks in agricultural production and their impacts on market prices of agricultural commodities. Using a literature review on crop production shocks, the authors identify the major factors determining such shocks to propose a hierarchy of the factors with the greatest impact. They also show that these factors are often interdependent, making crop yield forecasting difficult. Based on recent research projects, they show the potential of machine learning and probabilistic models to open a new avenue for predicting production shocks and their impacts on agricultural prices. This potential is connected to the development of open access databases and recent powerful algorithms. Finally, the authors discuss the economic mechanisms that link seasonal production forecasts with market impacts, and show how improving production forecasts could reduce price volatility.

Chapter 5 by Patrice Dumas, Agneta Forslund and Chantal Le Mouël explores the role of modelling frameworks to represent food diets and land-use change at a global scale. Starting with the observation that existing studies report very different results on the extent of the environmental impacts of food diets at the global scale, the authors advocate for more transparency when reporting simulation results of identical scenarios obtained from several different models. Their chapter points out the main mechanisms involved in the various models and emphasizes the extent to which these mechanisms explain the divergent results, hence contributing to clarify the debates. The authors focus on land-use change impacts caused by diet changes, and they simulate four contrasting diets with three models based on different modelling frameworks, including a biomass balance model, to widen the spectrum of the modelling frameworks considered.

The third section deals with agroecological innovations leading to dietary diversity.

Chapter 6 by Sandrine Fréguin-Gresh, Danièle Clavel, Hélène Guétat-Bernard, Geneviève Cortès, Valentina Banoviez Urrutia and Sandrine Dury concerns the valuation of the role of women in food and nutrition security. Although the role of women in food-related activities is widely recognized, few studies document the role of gender in agricultural and food systems or the relationship between gender and food and nutritional security. Based on a cross-cutting analysis of two case studies (Senegal and Nicaragua), the authors address the roles played by women in ensuring access to food for their households, including through agroecological gardens, the way these roles are maintained or reconfigured over time, and the way women negotiate spaces for action within productive and domestic spaces in order to guarantee household food security.

Chapter 7 by Ludovic Temple, Eric Malézieux, Denis Gautier, Christine Aubry, Jeanne Pourias, Raul Puente Asuero and Hubert de Bon deals with agroecological innovations, food and nutrition security and food safety for small farmers, with African-European perspectives. The authors address the question of the direct or indirect contributions of agroecological innovations in the improvement of availability and accessibility of high-quality food products. This issue of quality (encompassing nutritional, health and organoleptic dimensions) concerns farmers and practitioners of various forms of urban agriculture who want to strengthen their food security. The chapter examines the links between farming methods and dietary diversity through a cross-analysis of results on three contrasting case studies in Africa and Europe, analysing the diversity of these links, the methods used and the obstacles encountered.

The fourth section addresses the challenges of innovative processing of high-quality foods

Chapter 8 by Alain Kondjoyan, Valérie Guillard, Pierre-Sylvain Mirade, Thierry Goli, Antoine Collignan, Elodie Arnaud, Sandrine Costa, Nathalie Gontard and Nadine Zakhia-Rozis covers the issue of food loss and waste reduction in meat and fruit chains, and how food engineering could be a solution. The authors focus on the decrease in food quantity and quality at processing, distribution and consumption stages due to a lack of adequate processing and preservation technologies, and possibly a poor grasp of these technologies. They explore how the impact of processing technologies can be quantified in terms of mitigation of food loss and waste in meat and fresh fruits chains, such as by extending a product's shelf life and developing innovative processing and preservation technologies. They propose ideas to further reduce losses in these value chains through well-optimized processing and preservation technologies, using a generic food engineering approach.

Chapter 9 by Sylvain Rafflegeau, Germain Kansci and Claude Genot explores artisanal palm oil food chains in Cameroon, from quality design to consumption. The chapter aims to understand the links between the physicochemical and nutritional quality and production conditions of artisanal red palm oil from South Cameroon, and to identify the determinants of consumer choice for specific culinary applications. The authors relate the analytical quality characteristics of artisanal red palm oils to production conditions, and use field surveys to represent marketing and distribution channels of red palm oil from the industrial and artisanal producers to Yaoundé markets. Their analysis extends to the perception of product quality by consumers and the identification of various usages of red palm oil in local foods. Finally, the chapter provides a prospective analysis of artisanal production and artisanal and industrial consumption.

The fifth section looks at agroecology and resilient food value chains.

Chapter 10 by Geneviève Teil and Sylvie Lardon concerns the socio-economic and geographical perspectives on diversity, identity and resilience in the agroecological transition. The authors consider the concept of resilience as the result of a processing activity that relies on know-how, collective actions and methods of coordination between stakeholders. They propose a multidisciplinary perspective, combining socio-economics and geography, with examples from France, Italy and Brazil to show how actors use hybridizing modes of production, commercialization and multi-actor interactions to differentiate themselves. The authors discuss the way hybridization allows for sustainable farming and food activities, while aligning with the individual and collective strategies of the actors, hence contributing to territorial development dynamics.

Chapter 11 by Éric Vall, Claire Aubron, Stéphane Ingrand, Marie-Odile Nozières-Petit, Mathieu Vigne, Marie Dervillé, Eric Sodré and Charles-Henri Moulin addresses the leveraging of agroecology to improve milk production and marketing. The authors propose an original approach of agroecological transition, based on case studies focusing on low input or agropastoral milk production systems, predominantly family run, in Burkina Faso, India and France. They consider agroecology as a means of increasing demand for dairy products while accounting for the sustainability of natural resources and ecosystems. The chapter reviews the place of agroecology in each situation from the perspective of the FAO framework and discusses the remaining challenges regarding the mitigation of environmental impacts and the inclusive governance mechanisms for production and distribution channels in the face of market deregulation.

Section 6 is concerned with local resource management as a driver of food security.

Chapter 12 by Rémi Cardinael, Olivier Deheuvels, Louise Leroux, Julie Subervie, Akiko Suwa-Eisenmann, Cécile Bessou, Emmanuelle Bouquet, Thibault Catry, Regis Chikowo, Marc Corbeels, Gabriela Demarchi, Abdoul Aziz Diouf, Gatien Falconnier, Ndeye Fatou Faye, Jérémie Gignoux, Christèle Icard-Vernière, Camille Jahel, Pamela Katic, François Libois, Sabine Mercier, Claire Mouquet-Rivier, Talent Namatsheve, Andréa Renk, Ninon Sirdey, Isabelle Tritsch and Eric Verger explores the diversification strategies regarding food security and natural resources. The chapter deals jointly with two major issues faced by rural households in tropical areas: the conservation of natural resources and food security. The trade-off between profitability and sustainability underlying technical solutions to these issues is analysed through five case studies centred on diversification strategies: agroforestry in Senegal, cocoa-based agroforestry in the Peruvian Amazon, cereal-cowpea intercropping in Zimbabwe and sub-Saharan Africa, perennial palm oil monoculture in Indonesia, and extensive cattle production in the Brazilian Amazon forest.

Chapter 13 by Jean-Daniel Cesaro, Guillaume Duteurtre, Stéphane Guilbert and Nadine Zakhia-Rozis addresses the issue of managing urban food waste through the circular economy. The authors identify possible synergies within the food system between agriculture and cities to make food waste management more efficient. From a multi-partner and multi-sector perspective accounting for upstream and downstream sectors and the corresponding stakeholders, agriculture could be a solution for managing urban food waste. The chapter follows the production and recycling of food waste at different steps of the food system, i.e., in wholesale and retail markets, stores, restaurants and households. To show that a circular economy based on food waste valorization already exists around the world, with constraints due to sanitary regulations, the authors consider case studies on the cities of Montpellier, Chicago, Antananarivo, Dakar and Hanoi.

Chapter 14 by Perrine Burnod, Angel Avadí, Paula Fernandes, Frédéric Feder, Christine Aubry, Thibault Nordey, Laurence Defrise, Djibril Djigal, Audrey Jolivot, Stéphane Dupuy, Komi Assigbetsé, Hélène David-Benz, Coline Perrin and Valérie

Andriamanga examines challenges and innovations towards food security associated with market gardening in African cities. The authors study the effective contribution of intra- and peri-urban market gardening to urban food security, the way vegetable production evolves in a context of land competition, the role of social pressure in reducing environmental effects, and the technical and institutional innovations to reduce the use of inputs harmful to the environment and health. The chapter relies on case studies of market gardening at different scales – territory level in Madagascar, farm level in southern Benin and plot level in Tanzania and Senegal – and it combines different disciplines (economics, geography, agronomy, etc.) and methodologies (analysis of satellite images, quantitative and qualitative surveys, analysis of value chains, agronomic trials at experimental stations and on farms, etc.).

This book should appeal to readers interested in the ongoing transition towards more sustainable and healthier food systems at local, national and international scales. While researchers involved in the many dimensions of food security are a natural target readership for this book, we hope that a larger audience such as students and experts in national and international institutions as well as decision makers, civil society and other stakeholders will also benefit from these contributions.

We thank all the contributors to the book chapters, who participated in this ambitious exercise of summarizing years of research from GloFoodS projects, while also detailing the state of the art in their areas of interest and scientific prospects for future research. The chapters were carefully reviewed by scientists, both internal and external to the GloFoodS programme, whose expertise significantly contributed to the overall consistency and quality of these chapters. We would like to extend a special thanks to Marie-Josèphe Amiot, Anthony Fardet, Etienne Hainzelin, Pierre Gasselin, Eric Malézieux and Bertrand Schmitt. Finally, the editing and publishing team at Quae provided invaluable assistance in the preparation of this book. In particular, we thank Christelle Fontaine and Teri Jones-Villeneuve for having accompanied the editors throughout the publication process for this book.

Section I

Governance of food systems

Chapter 1

Governance matters… but is it what you think?

Arlène Alpha, Antoine Bernard de Raymond, Sandrine Fréguin-Gresh, Allison Loconto

Since the 1970s, food security has been framed as a technical problem to be solved mainly through technical solutions like green revolution technologies or market information systems (Fouilleux et al., 2017). In the 2010s, when nutrition began to be coupled with food security in international forums, the technology focus shifted to nutrient deficiencies and fortification technologies (Loconto, 2021). Overall, analysis of the successive definitions of food security – from the one focused on food availability to the one emphasizing also the access to food and the nutritional dimension – shows that they have not explicitly addressed issues such as inequity or power imbalances within food systems nor their governance.

Non-state actors have developed alternative framings of hunger and malnutrition around norms of justice, rights and sovereignty. For example, in opposition to the food security concept, which some view as restricting political debate, many social movements around the world have emerged to defend the concept of food sovereignty. The transnational peasant organization La Via Campesina advocates for food sovereignty as a way to re-politicize the fight against hunger and malnutrition. The food sovereignty movement is part of wider social mobilizations that developed across the globe in the mid-1990s as a critique of neoliberalism (Trauger, 2015). In the 2000s, this stance was most apparent in the resistance to World Bank/International Monetary Fund (IMF) structural adjustment conditionalities that required market liberalization, which led to the strengthening of food sovereignty movements in many developing countries. The 2008 economic and food crises marked an important turning point in the way the international food security agenda was governed. Starting with the reform of the United Nations' Committee on World Food Security and the establishment of its Civil Society Mechanism and High-Level Panel of Experts on Food Security and Nutrition, a number of UN and G8/G20 initiatives on food security and nutrition also emerged, thus changing the contours of food security governance and its analysis.

Diverging from a normative approach that judges whether policies are good for achieving food security, governance is used in this chapter as an analytical framework. This framework highlights the power struggles among actors as they propose different visions of food insecurity and solutions to this social problem (cf. Constance et al., 2018). This approach to governance not only concerns 'hard law' (regulatory frameworks, subsidies, taxes, etc.) but also metrics, models, standards, and the instruments that govern actors' conduct and represent different forms of 'soft law' (Bernard de Raymond and Thivet, 2021).

Following an explanation of this governance framework, we illustrate its usefulness in three different cases: a national food programme in Nicaragua, the resilience agenda and its operationalization in the Sahel, and land-use modelling. We conclude by explaining why such an approach is essential when analysing food security, since ostensibly neutral instruments have the power to influence the possibilities for action, which in turn shape actors' behaviours.

⏩ Analysing food security through the lens of governance

Two broad concepts of governance are present in public debate and in academia. The first is a normative approach, in which governance refers to a gentler way of organizing behaviour and coordinating actors that has emerged as part of the neoliberal project of reorganizing state-market-civil society relations (Jessop, 1998). In this form, governance is a multi-stakeholder vision of governing that promotes more inclusive processes of deliberation and decision-making (Lowi and Nicholson, 2015). There is a profoundly political element to governance, as those who promote different visions of the future tend to define it in terms that are consistent with their own normative visions. For instance, neoliberals define 'bad governance' very specifically in terms of the existence of inadequate markets and excessive state control. Others define governance from the perspective of a democratic deficit, defining it therefore in terms of transparency, accountability, fairness and participation (i.e., the 'good governance' agenda). Both such normative approaches have strongly influenced food security policies, but critics claim that focusing on a wide variety of one-size-fits-all indicators for the 'goodness' of governance most likely undermines efforts to govern (Sundaram and Clark, 2015).

This inadequacy of indicators brings us to the second definition of governance, which is based on the Foucauldian notion of *gouvernementality* (i.e., the conduct of conduct). Foucault (1997) places the focus of governing on the 'disciplining' of bodies in a population. In this version, governance covers a range of practices that 'constitute, define, organize and instrumentalize the strategies that individuals in their freedom can use in dealing with each other'. This idea of instrumentalization has been expanded upon in political science to shift attention away from actors' discourses and interests towards how they are embedded in specific public policy instruments (Lascoumes and Le Gales, 2007).

Studies in this vein have focused on classic public policy instruments that are under the state's authority, such as regulations, laws, financial instruments, subsidies and taxes. However, with the neoliberal priority of state withdrawal from several sectors in the 1980s and its replacement with multi-stakeholder governance, increasing attention is paid to 'soft law' instruments. These include charters, evaluation tools, models, standards and discourse that can influence not just debates in forums and arenas, but also the type of knowledge that informs public policy and debate.

A growing body of literature has examined the role of models (e.g., economic, geospatial, agronomic and computer-simulated models) in the global governance of agriculture and argues that models work to enact the visions they project (Cornilleau, 2019a, 2019b; Loconto and Rajão, 2020; Tétart, 2020). Similarly, an emerging body of literature focuses more specifically on instruments of measurement (metrics and indicators) that have been fundamental in the development of goal-oriented policies (Cabane and Tantchou, 2016; Kanie and Biermann, 2017). This literature shows that governance patterns and processes themselves have become an 'expertise of political practice and process' (Dingwerth and Pattberg, 2009). Indeed, the knowledge of experts (particularly agronomists, economists and development experts) has long been privileged over that of other types of knowledge in food and agriculture policy (Cornilleau, 2019b; Loconto and Fouilleux, 2019). This expert knowledge approach has been accompanied by a strategy to quantify and objectify policy (Diaz-Bone and Didier, 2016), a hallmark of neoliberal governance (Desrosières, 2014; Porter, 2015).

By adopting this second approach to governance, we can see more clearly who is governing and why. We can thus ask: Who has the power to define the rules that others must follow? Who influences the creation and design of policy instruments that serve the interests of different actors? How do the developed instruments shape the possible actions once they are taken up by the subjects of public policy?

⏩ Three perspectives on food security governance

We address the abovementioned questions in this section by exploring three case studies carried out under the GloFoodS programme: a national instrument for food sovereignty, a regional instrument for resilience in food aid, and a set of international instruments for modelling land used for food production.

The limits of a national instrument for food sovereignty policy: the Zero Hunger Programme in Nicaragua

Nicaragua is a low-income country in Central America, marked by a tumultuous history linked to multiple crises and natural disasters. With about 17% of its population still suffering from hunger, Nicaragua remains one of the most food insecure countries in the Americas. Food insecurity is mainly found among the poor and rural populations who are affected by multidimensional poverty (INIDE, 2016). Gender and age inequalities, degradation of natural resources, isolation and limited access to services exacerbate poverty and food insecurity.

To address these problems, agricultural and food policies evolved conjointly in Nicaragua. These policies were designed as import substitution policies focused on agro-export production to generate foreign exchange in order to import food to meet local needs (Fréguin-Gresh and Cortès, 2021). However, in the 1980s, a radical change occurred: the Sandinista revolution of 1979 promoted new policy directions and focused on transforming the food system, addressing land issues and improving the social conditions of agricultural production. While agro-export production remained essential, policies first targeted the peasantry (Zalkin, 1987) and gave priority to rural and urban food self-sufficiency (Austin et al., 1985). In the 1990s, the return to power of liberal governments again prioritized agro-export production in a context where the population, and especially marginalized populations (e.g., indigenous people, farmers, women and children), was extremely poor and hungry. Few public interventions addressed those issues, with the exception of limited, targeted actions focusing on child nutrition that were funded by international aid.

Since the early 2000s, a series of policy shifts occurred, thanks to the initiative of a coalition formed by social actors and Sandinista deputies in resistance to the institutions established by the government and supported by elites and multilateral organisations. Emerging in the debates as a reaction to the Uruguay Round negotiations of the World Trade Organization, which advocated food security through the market (Godek, 2014), the concept of food sovereignty was progressively introduced into the national agenda and translated into a draft of a national food and nutritional security policy. In 2007, Ortega was re-elected to the presidency. While his government ensured some continuity of macroeconomic policies, a new policy shift was nonetheless observed. The new government strategy, called the National Human Development Plan (PNDH), profoundly reoriented the content of the policy frameworks towards the fight against poverty and hunger. Based on old diagnosis, a new comprehensive rural policy was designed, following the enactment of the Food and Nutritional Security and Sovereignty (SSAN) law in 2008, known as Inclusive PRORURAL. The law targeted family farming, poverty reduction, adaptation to climate change and strengthening food security. Inclusive PRORURAL was designed as both an agricultural and food policy that revolved around three programmes: 1) a national food programme (PNA), which included a Zero Hunger programme; 2) a national agro-industry plan (PNAIR), and 3) a national forestry programme (PNF).

The Zero Hunger programme was based on the distribution of productive asset transfer (*Bono Productivo Alimentario*, or BPA, in Spanish). In addition to a clear reference to the Brazilian Public Policy 'Zero Hunger', the BPA instrument was inspired by the work of a Nicaraguan economist named Orlando Núñez Soto, who founded an ideology for agrarian development elaborated during the Sandinista revolution (Núñez Soto et al., 1995) and became the presidential advisor on social issues in 2008. The objective of the BPA instrument was to provide women with the means to acquire productive resources such as livestock, equipment and agricultural inputs. The SSAN law established a twofold aim for the BPAs: to ensure sufficient income for rural households, and to guarantee the right to healthy, sufficient and adequate food for all. The law also placed food sovereignty front and centre, promoted the environmental and economic sustainability of the food system, and sought inclusion, with an emphasis on women, children and young people. It provided services to actors in different value chains, prioritizing staple foods (rice, beans, maize, sorghum, meat and dairy), the rural sector, and small and medium producers.

The BPA instrument was a livestock productive asset transfer programme for women who were identified as poor, so to strengthen their families' food production capacity and wealth. Aid was provided in the form of agricultural inputs (e.g., cows, seeds, tools, construction materials) according to criteria defined by the instrument and interpreted by technicians working in the region. Beneficiaries also received technical assistance, training and financing, and were required to manage a savings account to earn a surplus of 20% of the value received through a rural credit union for the development of their villages. The Ministry of Family Economics (MEFCCA) was responsible for operational planning while its technicians handled local implementation.

However, the way the BPA instrument was actually implemented was controversial (Fréguin-Gresh and Cortès, 2021). In the 1980s, when many revolutionary leaders lacked technical and managerial skills, local organizations played a central role. The Cabinets for Family, Community and Life – organizations inspired by the Sandinista Defense Committees (CDSs) – were instrumental in choosing beneficiaries. The role and legitimacy of these organizations was contested from the very beginning. While their mandate was to strengthen citizen-state relations and to stimulate social participation in field-level decision-making, the Cabinets carried out technical inspections and influenced the choice of beneficiaries, theoretically in coordination with administrative actors. Their legitimacy depended on local political forces and the personal ethics of their representatives, making their role in programme implementation a sensitive issue (Kester, 2009; Finnegan, 2011). Indeed, some Cabinets showed a selection bias between women engaged in local politics and those who were not. This called into question the principles of universality and non-discrimination promoted in the SSAN law. In addition, a clientelistic system – consistent with the decades-long tradition of political and economic activities in Nicaragua – quickly formed (Envío, 2015). As a result, the effectiveness of the BPA instrument was mixed. Although it was implemented throughout the country, the number of beneficiaries remained too low, which might be explained by the restrictive beneficiary selection process. In addition, men were often beneficiaries instead of their wives. At the time, women rarely owned the family plots, which was an eligibility criterion (i.e., demonstration of access to the land needed to feed the animals). The composition of the food production vouchers was subject to fierce discussion and tensions (Kester, 2009; Finnegan, 2011). Following an initial provision of cattle (or pregnant cows), women beneficiaries of the BPA instrument received pregnant sows and small backyard animals. This shift in rule interpretation effectively confined women to the home where 'traditionally' they were responsible for domestic tasks. Although the Ministry of Family Economics provided capacity-building to beneficiaries to increase farm productivity and promoted women's associations and empowerment, it did not take into consideration the change in power relations within the household. Nor did it break the historically gendered division of labour (see chapter 6), which remains a source of high vulnerability for women's food security.

The BPA instrument illustrates how rules such as beneficiary selection criteria, their interpretation by technicians, and the politics of local actors responsible for a programme's implementation can thwart the stated ambition of empowering women to strengthen food sovereignty.

Who governs food security in countries 'under an aid-regime'? The case of the resilience agenda in Sahel

Studying governance actors is of great importance as each actor often has a unique understanding of a public problem with tailored solutions. The resilience agenda, which took hold in international development aid policies in the early 2010s, illustrates this point. Before this agenda, food security was usually depicted as an agronomic production problem or a market failure. However, the resilience agenda has sanctioned the rise of another conceptualization of food security – one that is embodied by emergency, public health and social protection actors. This idea of food security emphasizes its nutritional dimension, and the importance of interventions in the fields of health, hygiene, education and social protection to achieve zero hunger.

The initial concept of resilience was borrowed from the field of materials physics and refers to the ability of a structure to return to its initial state after a shock (Holling, 1973). It has gradually gained acceptance in international discourse with the rise in crises and disasters (Lallau, 2014) and the idea that crises are becoming recurrent phenomena in the context of climate change. Improving the resilience of populations, countries or territories against such shocks is a governance challenge requiring coordination between the two disparate worlds of emergencies and development. In West Africa, the introduction of resilience to food insecurity discourse arrived later than in other regions (Vonthron et al., 2016) and was linked to the 2005 food crisis in Niger. The Niger example highlights the fact that food crises can no longer be seen as cyclical episodes, but that they have structural causes and, above all, long-lasting consequences (Galtier, 2012). Decapitalization (i.e., the sale of livestock by households to cope with a crisis) is a clear example of a long-term consequence of a crisis. Introduced by British and American national development agencies, the resilience agenda was promoted by the European Commissioner for International Cooperation, Kristalina Georgieva (now managing director of the IMF), starting in 2011. The Food and Agriculture Organization of the United Nations (FAO) also contributed to the resilience agenda in West Africa; a full team called 'the resilience team' was set up in 2016 in the FAO's subregional office for West Africa dedicated entirely to dealing with the protracted food security crisis in the Sahel region. The objective of better prevention and response to crises embodied in the resilience agenda translates into a call for cross-cutting, multi-sectoral approaches, beyond the agricultural and food sectors. The resilience agenda thus provides an opportunity to introduce issues related to nutrition, health, hygiene, education and social protection into the governance of food security.

Resilience is thus a polysemic term, now part of a global strategy to fight poverty, supported in particular by the World Bank. The World Bank does not rely solely on productive investments and their benefits in terms of economic growth, but on multi-sectoral interventions targeted at the most vulnerable who do not benefit from the effects of economic growth. In principle, resilience is not a new policy characterized by a specific object or domain, but a marker to assess and rationalize existing policies. The resilience agenda goes hand in hand with a desire to contribute to the construction of social welfare states in the Global South. In particular, the aim is to establish the foundations of a social protection system through the financing of safety nets for the most vulnerable. In West Africa, it is implemented through the Global Alliance for Resilience Initiative (AGIR), launched by the European Union and the Economic Community of West African States (ECOWAS), West African Economic and Monetary Union (WAEMU) and Permanent Interstate Committee for drought control in the Sahel (CILSS) countries in 2011.

Given these stated ambitions, what can be said about the implementation of the resilience agenda? Here, we can see that the concrete scope of the resilience agenda is largely conditioned by its financing and implementation instruments. Two elements are particularly salient. First, in countries 'under an aid regime' (Lavigne-Delville, 2017), resilience is implemented through the country-specific resilience priorities adopted at the national level. The resilience agenda functions not as a cross-cutting marker but as a new policy with a dedicated budget, expected to be funded by donors. Second, this approach of relying on donors echoes the logic of operations and project-based financing of many western donors and NGOs present in the region. The projects implemented by these NGOs certainly make it possible to broaden the range of interventions in the field of food security (e.g., cash transfers, nutrition-sensitive agriculture). However, such interventions generally remain confined to a locality or region and frequently demonstrate the limits of this approach for the sustainability of benefit provision. This mode of operation poses problems for consolidation, coherence among numerous interventions, and long-term maintenance of the proposed initiatives in relation to the objective of building a social welfare state.

The case of Sahel resonates with other countries 'under an aid regime', such as Haiti, which also illustrate the tensions between national actors, international organizations and donors. The analysis of the interplay of actors in the development of Haiti's National Strategy for Food Sovereignty and Security (Crétois, 2018) highlights additional problems with this form of governance. First, it shows that existing institutions are not being challenged, despite a broad and inclusive participatory process. Second, it underscores the impossibility of reaching a compromise, because the strategy is based on the juxtaposition of ideas and proposals for action rather than on the search for clear policy directions. Finally, the participatory nature of the process is severely hampered by the fact that actors with influence and decision-making power (importers) are not invited to the discussions, and those concerned with food security issues (civil society) lack the capacity to effectively participate in these forums.

Who governs when models are the instruments of governance? The case of land-use models in food security policy

Achieving food security at a global scale while protecting the environment, as envisioned in the Sustainable Development Goals, requires a complex process of collaboration and the integration of analyses and actions at multiple scales. This goal-driven agenda is part of the most recent wave of evidence-based policymaking in global governance (Kanie and Biermann, 2017). A range of approaches are used to articulate these future visions and to identify the indicators that will measure progress and the type of data that will be accepted as evidence. Since the 1970s when the first models developed by the International Institute for Applied Systems Analysis (IIASA) were used to build bridges across the cold war divide (Bonneuil and Fressoz, 2016), scientific cooperation to confront problems on an international scale (e.g., climate change and energy transitions) has grown in importance (Aykut and Nadaï, 2019). A prescient question in policy debates on food security is: Can we feed the world with our current land use? To answer this question, modelling agricultural and land use is now used as a means to envision future land access, use and management in different agricultural production systems (Lambin et al., 2000).

One of the key promises of land-use models – understood here as a range of instruments for describing, explaining, projecting, predicting, prescribing, planning and managing the use of land – is the ability (or at least the ambition) to provide comprehensive representations of the world and reveal the underlying 'real' causes of specific land-use configurations (e.g., high yields) and changes (e.g., deforestation) (Riebsame et al., 1994). Accordingly, it is expected that land-use models will allow decision makers to devise evidence-based policies that are more effective than those based on traditional political negotiation. Land-use modelling builds on a long tradition of cartography as a quintessential instrument of state power (Scott, 1998). Critics of this form of governance claim that the over-reliance on land-use models might lead to the distancing of government officials from local communities, as modelling can lead to selective imaging of communities' social reality (Rajão, 2013). Once a reality is removed from a model, decision makers do not see them and important aspects of social life remain invisible and are not addressed by their policies (Pickles, 1995).

Modellers and social scientists thus argue that a plurality of modelling methods improves knowledge, policy and democratic processes. This is because specific models govern the gap between modelled and material reality in different ways. Amazonian deforestation models are 'drivers': they produce virtual realities with real effects on the ground such as large-scale dams, roads and bridges. This has turned the Amazon from an unmanageable forest into a legal place for export extraction (Hecht and Rajão, 2020). In measuring high carbon stock, forest classification models are 'composers' that exclude land-use temporalities, which in turn means that small and indigenous farmers' use of 'degraded' land through rotations or grazing does not fit within a clear classification (Cheyns et al., 2020). The result is the devalorization of this type of land for local food security needs.

With regards to the well-known land sparing model used to determine which farming system is best for nature while still ensuring enough food to eat, we found that these models are 'performative', i.e., they reproduce not just their assumptions on the ground, but also their worldviews (Loconto et al., 2020). The result is that the most intensive producers have better outcomes for nature and modellers argue they are better able to ensure food security. By mobilizing a network of like-minded scientists, significant evidence was produced that was easily simplified and incorporated into industry adaptations of life cycle analysis tools. These tools were used in turn to select commodity suppliers who were using the least amount of land for a given volume of crop. The incorporation of these same metrics and knowledge into sustainability standards meant that intensive production was also certified as sustainable. In reality, the result is an expansion of intensive agriculture and a strengthening of the power of these actors in the market and in the agribusiness sector – to the exclusion of small producers – all without solving either environmental problems or food insecurity.

In the Agribiom model, used to determine how much food is needed for the future, models are 'boundary objects' that produce real virtualities (e.g., scenarios) (Dorin and Joly, 2020). The authors explore an alternative modelling exercise that was developed as a participatory foresight model with the specific intention of supporting public debate, rather than predicting outcomes. They argue that when the political stance of using a model as a 'learning machine' rather than a 'truth machine' is adopted, some virtual realities, processes and actors that were invisible in mainstream predictive models can enter into both scientific and public debates.

Exploring the ways in which models govern leads us to a more nuanced understanding of the politics of models and the invisibilities of their use in food security policy. By providing detailed accounts of how scientists work and interact, modellers become human products of situated social contexts, rather than simply numb instruments of modern capitalism. This is clear, for instance, when Hecht and Rajão (2020) show that the colonization of the Amazon was a civilizing dream shared with land-use modellers rather than the mindless destruction of nature. In many cases, scientists and experts are aware of the consequences of those trade-offs, but they must also negotiate with multiple demands and the need to provide objective answers to policymakers. Cheyns et al. (2020) show that the focus of scientists on carbon sequestration, which brings with it the possibility of participating in markets for carbon as a tradable commodity, has overlooked civic notions of justice for the rural palm oil producing communities. Likewise, Wolf and Ghosh (2020) show that the policy decisions to optimize a model and market for only one nitrogen management practice in one crop has overlooked a range of diverse nitrogen management practices that may better reduce nitrogen emissions. As a result, industrial-scale farming benefits from such situation at the expense of both effective climate change mitigation and small farmers' livelihoods. Here, the visible outcomes are more the consequence of institutionalized practices by public actors that produce evidence (i.e., it is easier to model a monoculture crop than a complex agroforestry system) than adherence to a specific political agenda.

These examples demonstrate that the increasing use of models in food security governance is a 'double-edged sword'. Modelling allows public actors to 'visualize' land and its use in food security discussions (e.g., what to include/exclude, prioritization of short-term production or long-term productive ecosystems), but without thoughtful support upstream of what is modelled. The models risk changing the very reality of the objects to be governed.

⏩ Conclusion

The concept of food security has a well-established definition around four pillars – food availability, access to food, food utilisation and stabilisation – that is the result of years of global debate and international consensus. However, the case studies presented in this chapter show that a global definition does not remove the tensions that exist between actors who hold different visions of the problems responsible for food insecurity, nor the solutions that should be applied. In various national, regional and global contexts, these cases underscore the importance of studying who defines food security through the development of specific instruments and who implements them. The approach used by several GloFoodS-funded projects to examine governance through its instruments demonstrates that the operationalization of discourse through these instruments varies greatly. Very often, the discrepancies that exist between the discursive visions and what is governed can be explained by the way the instruments are designed and used.

This form of governance raises concerns about the representation and legitimacy of actors (i.e., who speaks for the hungry? who takes ownership of the problem?). However, it also calls into question the instruments themselves and the types of knowledge and power that can be embedded in them. The creation and use of instruments are linked to certain worldviews and their application by actors reproduce these worldviews, hence their capacity to govern the 'conduct' of food security. There are winners and losers depending on the mode of governance that is introduced by the instruments. Our analysis calls for paying particular attention to the inequalities that governance instruments produce or reinforce, whether consciously or not. From this perspective, the existence of a plurality of instruments in a public policy approach to food security not only improves knowledge, but also contributes to strengthening democratic processes that allow for the debate of worldviews.

Finally, while scholars tend to focus either on global food security governance or on governance in specific national contexts, a promising avenue that emerged from looking across these three projects is to study the interactions among scales. In addition to studying the circulation of actors and ideas between scales, it would be interesting to look at how each scale is constructed as its own situated context of food security and the ways that actors and instruments enable these contexts to interact. Indeed, many local forums (e.g., food councils) are not necessarily connected with international debates, yet they may still be strong levers of change at other scales of policy implementation. In addition, in the digital age, the dynamics of interaction among actors, at different scales and between scales, are increasingly constructed with the collective mobilization of actors. Finally, we see a clear shift in the focus from individual experts towards a role for networks to play in linking different forums of policy action (such as the ambition of the Milan Urban Food Policy Pact to create a global network of city-level food systems).

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Chapter 2

Land management, value-chain governance and food security: examples in Senegal, Morocco and France

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Food security is commonly tackled as a problem of food availability, affected by climate and storage capacity limitations, or as a poverty-related problem of food access. A growing body of literature shows that public bodies can foster food security by acting on the essential levers of farm households' livelihoods, such as access to land and markets. In addition to public policies, the actions of private macro-stakeholders play a key role with regard to how land transactions are handled and the way agricultural products are traded. Finally, land governance is frequently associated with the governance of value chains. Private operators in Africa invest in agricultural production, processing and trade through contracts, which are often associated with land grabbing (Cotula et al., 2009).

Governance has become a major research agenda in many areas of social sciences, especially with regard to land management, territorial development and value chains. A key issue that arises is coordinating the decisions of stakeholders with connected but sometimes diverging interests (Chia, 2013). Governance is an intermediation process aimed at negotiating arrangements to reach compromises to address heterogeneous interests. The idea of land ownership constitutes 'all relations between individuals and the property (and the renewable natural resources that it supports' (Rochegude, 2005, p. 59) or 'the specific set of social relations based on the land or territorial space' (Le Bris et al., 1991, p. 13).

Governance of a value chain relates to the 'relations of authority and power that determine how financial, material and human resources are allocated and circulate within the chain' (Gereffi and Korzeniewicz, 1994, p. 97). Governance modes vary between the market – characterized by spot transactions coordinated by price with no commitment – and the hierarchy, where supply is controlled by administrative processes. Contracts are intermediate modes of governance with joint commitments related to conditions of production, delivery and purchase. They often come together with upgrading, i.e., the process by which stakeholders acquire new capacities and reach new markets (Humphrey, 2004).

The territorial governance approach addresses the issues of stakeholder guidance and participation. Territorial governance is the 'dynamic process of coordination between public and private operators with different identities and asymmetric resources around territorialised issues' (Rey-Valette et al., 2011). The forms of coordination vary according to the level of participation of the different groups of stakeholders within the territory (Beuret, 2006), ranging from communication (stakeholders from outside the territory disseminate a message concerning a decision) to negotiation (joint construction of a decision). This framework is dynamic, because organizational and institutional innovations can alter this level of participation. Participation can take the form of cooperation among different groups of stakeholders or the form of conflicts, which represent a means for excluded parties to rejoin the negotiation process (Chia et al., 2008).

In this chapter, we examine the governance of land and food value chains and its impact on population livelihoods. The chapter covers work conducted in Senegal, Morocco and France. The research in Senegal combined territorial governance with value-chain governance through agribusinesses and observed their effects on agriculture sustainability and the inclusion of smallholders and food security. The work in Morocco focused on the development of an industrial zone, driven by public investors but with limited regulation by public authorities to the detriment of multifunctional nutritive agriculture. The research conducted in France focused on local levers used to regulate land use.

We assume that the evolution of value chains and access to land are linked together in various ways. First, in sub-Saharan Africa, the modernization of agriculture, which is driven by agribusinesses and characterized by vertical coordination, large-scale production and crop intensification, puts considerable strain on the land. The effects may be negative if this strain triggers a more intensive use of inputs, specialization of production and the exclusion of extensive land uses (e.g., pastoralism), and even more so when investors seek out countries with weak governance and land security (Arezki et al., 2011). Second, in peri-urban areas, land use for agricultural production is jeopardized by urban pressure due to industrial and housing projects. Such uses impede the capacity of cities to rely on short value-chain procurement or benefit from the multifunctionality of peri-urban agriculture (Duvernoy et al., 2005). These effects are mitigated by public action and territorial governance. The three case studies in this chapter (see Table 2.1 for an overview) illustrate some of the local levers that are used. The case studies explore the precise characterization and actual functioning of these levers, and provide a balanced view of their advantages and shortcomings.

Table 2.1. An overview of data.

Location	Level of governance/ approach	Effects	Data source
Senegal River Valley, Dagana department[1]	Rice value chain (producer-processor relations) – global value chains framework Land (setting up of agribusinesses)	Access to land for agricultural producers Agricultural practices (use of chemical inputs)	Case studies on three agribusinesses: 154 semi-structured interviews with various actors in the value chains and from development and research organizations One workshop with producer and agribusiness representatives Survey of 470 farmers about their incomes and food insecurity
Morocco, region of Casablanca[2]	Peri-urban land (establishment of an industrial zone)	Access to land for agricultural producers	In-depth interviews with 20 stakeholders in the land system (farmers, promoters, employees in the local communities)
Île-de-France[3]	Peri-urban land (SAFER pre-emptions)	Access to land for agricultural producers	Analysis of 784 SAFER pre-emptions Interviews with 15 municipal employees and elected officials

1. Soullier et al. (2018).
2. Lenseigne and Bignebat (2019).
3. Belleil (2018).

⏩ Limited counterbalancing governance facing agribusiness in Senegal

The administrative department of Dagana comprises three agroecological zones where small-scale producers carry out different activities (Figure 2.1). In Walo, located between the Senegal River and the main road, irrigated land is primarily used to grow rice, and to a lesser extent, for market gardening. Ferlo, a sandy and arid zone covered by shrub and wooded steppes, is located south of the main road. Pastoralism is the main activity in this area. In Diéri, which includes Lake Guier and surrounding farmland, agriculture is diversified. Agricultural activities are primarily carried out by family farmers, who mostly belong to the Wolof and Moorish ethnic groups, whereas the agro-pastoralists are mainly Fulani. The agricultural resources are governed by a combination of customary and legal institutions (Kamara 2014). The customary institution has for centuries been shaped by the practices of agro-pastoralists, for whom the territory is very valuable for their identity. This institution advocates collective ownership of agricultural resources, whereby descendants inherit the right of use. It endeavours to limit conflicts relating to the use of agricultural resources, such as by encouraging complementarity between crops and livestock. The municipal councils define the land-use plan and manage allocations for housing, crops and livestock. The state manages land allocated for ecosystem protection. Territorial governance sometimes combines these customary and legal institutions. The local and state authorities have thus, in part, called on the customary institutions to allocated land linked to the expansion of irrigated areas. However, these institutions do not always agree, and they sometimes allocate conflicting functions to the same resource. For instance, the Ndiael nature reserve has been used for pastoralism for centuries.

In the wake of the 2007 food crisis, the public authorities and international organizations strengthened their actions to develop the Senegalese agrifood sector. The main levers were focused on encouraging large-scale investments, intensifying agricultural practices, increasing land development, promoting contracting and developing infrastructure (Tyrou, Ribier and Soullier, 2019). These projects have helped transform the country's value chains through three agribusiness firms specialized in rice, tomato and agrofuel.

The investments made by the three agribusinesses have had different effects on territorial governance (Figure 2.1). The company Coumba Nor Thiam has local roots. It negotiates with rice farmers and takes customary rules into consideration. The company has gradually increased the capital it has invested in rice production and processing, and negotiations with producers enabled it to lease 1000 hectares in 2014 and conclude contracts with 660 producers. West African Farm, an English firm investing in the Diéri area since 2011, has also negotiated with local producers. Through its employees, it directly manages market gardening operations covering 200 hectares allocated to it by the municipality of Ngnith in exchange for a contribution to the municipal budget. The company does not source products from local producers but has constructed a canal to irrigate 200 hectares of land farmed by local producers. Meanwhile, Senhuile-Senethanol has relied on political support to impose its presence on agro-pastoralists in the areas. It is an Italian-Senegalese firm that has obtained access to 20,000 hectares located within the Ndiael nature reserve to produce biofuel. Despite certain investments benefiting surrounding villages (schools, health centres, mosques), its activities block the rangelands and access to watering points (Papazian et al., 2016). The producers excluded from the negotiations have therefore reintegrated the territorial governance process by setting up an association in order to negotiate with public authorities and the company.

Small-scale producers are affected differently by the agribusiness investments. The Fulani agro-pastoralists have seen their access to land reduced because the investments lead to the extension of farmed areas and reduce grazing land. While the arrival of West African Farms has given various producers access to irrigated land, the investments made by Senhuile-Senethanol conflict with the activities of some 9,000 agro-pastoralists. A total of 16.16% of the agro-pastoralists surveyed declared that land grabbing is a reality on their land.

When an agribusiness firm concludes a contract or integrates rice farming into its operations, agricultural practices do not necessarily change (Soullier et al., 2018). Rice farming by small-scale producers, whether contracted or not, is still intensive because it relies on the use of chemical fertilizers and herbicides. Nevertheless, the agribusiness firms do produce more overall (1.95 crop rotations per year compared to 1.15 for smallholders). This reflects the companies' efficiency by having access to inputs and investments when they need them to ensure two consecutive rice farming seasons. Furthermore, the agribusiness firms use slightly fewer inputs, most likely to limit the economic risks linked to soil fertility losses.

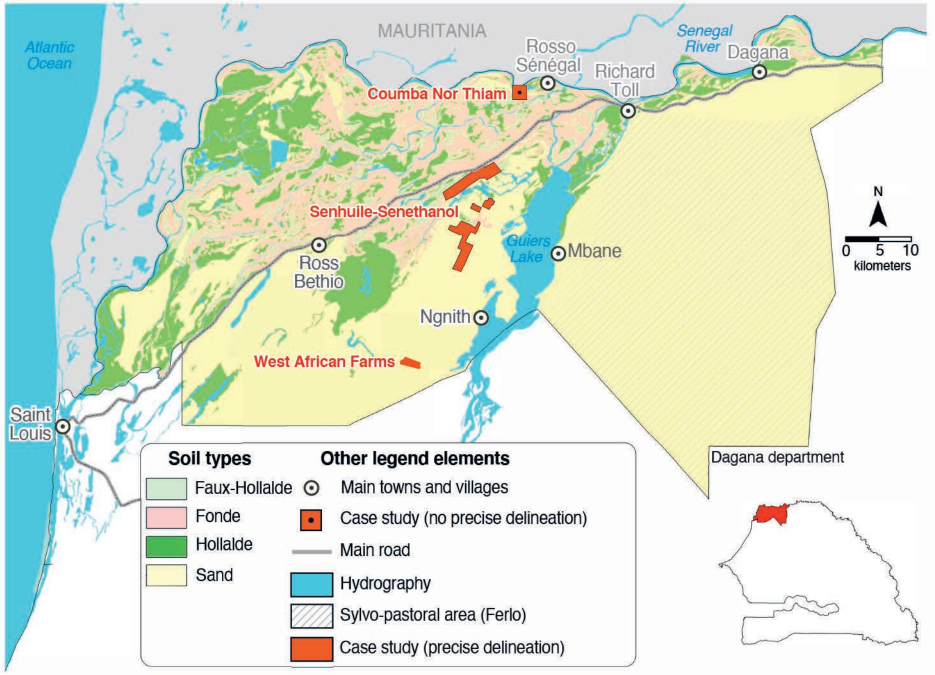

Figure 2.1. Holdings of the three agribusinesses in Senegal. Source: Adapted from Soullier et al., 2018.

The effects on the income of the different producers are limited. On one hand, 11% of the agro-pastoralists and 9% of the diversified producers who were interviewed are salaried employees, working for Senhuile-Senethanol and West African Farms, respectively. However, the income of some producers in the vicinity of agribusiness firms have fallen because of land grabbing (especially by Senhuile-Senethanol). On the other hand, previous research reveals that producers do not earn a higher income when contracting with a rice processor (Soullier and Moustier, 2018). Marketing contracts, which specify quality criteria, do not include any type of quality bonus, while production contracts, which include the provision of inputs and technical advice, are signed by rice farmers who are in debt to the national agricultural bank. This type of contract enables them to continue their activity but includes a significant insurance premium and high interest rates, reducing their profits by some 38.81%.

There is a wide range of effects on the food insecurity of producers. Producers working for agribusinesses can allocate their additional income to food, whereas those whose activities are restricted by agribusiness firms fall into severe food insecurity. Furthermore, industrial rice farmers who have signed a marketing contract can reduce their food insecurity, since this type of contract lowers farmgate price variability. Households can therefore more reliably predict the amount of the harvest to sell in order to repay their outstanding loan, and thus the amount they can keep for their own consumption (Soullier and Moustier, 2018).

⏩ Casablanca, Morocco: an emerging system of governance, as illustrated by the Ouled Hadda industrial zone

The demographic context in Morocco is typified by strong pressure on urban zones due to demographic growth and rural exodus. A major part of the urban population lives in a handful of large towns (Schaffar and Nassori, 2016).

A quarter of Morocco's urban population lives in the Casablanca-Settat region, which covers 2.7% of the national territory (HCP, 2020, figures from 2014). While its agricultural potential is recognized (with around 15% of the national total cultivated area), the region also plays a decisive industrial role. It generates 74.5% of national industrial production in terms of value and attracted over 80% of industrial investments in the country in 2015.

The industrial zone of Ouled Hadda is the perfect illustration of this context. It is situated in the province of Mediouna (bordering Casablanca), around 15 kilometres south-east of the centre of Casablanca in the city's immediate outskirts. It was chosen for the case study because of its high agricultural potential and attractiveness to new business.

Data were collected through a long-term field study that was carried out from June to December 2018 in Casablanca and the surrounding area.[1]

The Ouled Hadda industrial zone is part of the Sidi Hajjaj Oued Hassar Municipality, which had just over 20,000 inhabitants and covered around 10,000 ha of land as of 2014. At this same date, the industrial zone's potentially utilizable agricultural area was estimated at 68% of the total surface area, including 300 irrigated ha of privately-owned lots (known as *melk*) ranging from medium to large size (7.7 ha on average). Three quarters of these lots were occupied by the owners. The agricultural purpose of this land is, moreover, formally set out in a master urban planning document developed by the Ministry of Urban Planning and approved by the Ministry of Internal Affairs in 1984.

The zone attracted private industrial investments (mainly from the plastic and steel industries) as early as 2004 when land was acquired by private stakeholders with a view to building warehouses along the N9 highway. Official permission for construction rights was granted for a specific area, an industrial zone in Tit Mellil,

1. The results presented are based on around 20 interviews (Lenseigne and Bignebat, 2019) with Mediouna's Chamber of Agriculture, the urban agencies of the National Office of Agricultural Council and the Provincial Directorate of Agriculture and with a central property development agency, the Agricultural Development Agency, as well as with three farmers from the Mediouna province. Here, we mainly make use of two semi-structured interviews with: 1) Casablanca's Regional Investment Centre, which is in charge of allocating waivers (known as *dérogations* in French) concerning land use to enable construction of the biggest regional business projects, and 2) Casablanca's Wilaya, a regional body run by the Ministry of Internal Affairs. The first-hand information obtained was then completed through the study of official websites and policy documents issued by Moroccan authorities: the Urban Agency, the Regional Investment Centre and the Ministry of Urban Planning. Furthermore, the most thorough attention possible was paid to articles in the Moroccan press. A geographic study of land use carried out via Google Earth Pro© software then rounded out our data.

on the eastern side of the municipality. In the pipeline since 2007, the Ouled Hadda industrial zone has been recognized by the authorities in charge of urban development (i.e., the Urban Agency, the Regional Investment Centre) mainly as a reaction to investors using derogations to set up new businesses. This way of overriding usual rules (by special dispensation) was authorized at a national level in 1999, in order to make obtaining construction permits easier for projects that did not fall within the scope of the regulatory conditions in force at the local level (Es-Sallak, 2018). Frequent recourse has been made to such methods in the zone under study (La Vie Eco, 2011). Following the development of a dense industrial network, the industrial purpose of the zone was officially acknowledged by Casablanca's master urban planning document in 2010. At that time, it was the largest industrial zone in Morocco, covering 840 ha of the municipality's land.

Once Ouled Hadda had been declared an industrial zone, a public-private partnership was established in which the industrial partners largely funded the servicing of the site. Working together as an economic interest group, they were asked to pay for the site development as part of an agreement signed with the Regional Investment Centre. The Sidi Hajjaj Municipality does not appear to have been consulted at any point in the development process of this industrial zone, its financial means having been judged too limited to fund such a development.[2] Therefore, the municipality was not granted the right to be involved in the decisions in a national system where a decentralized decision-making process is at an early stage and where the private stakeholders have a large negotiation power and face legal flexibility (special dispensations).

In conclusion, this study has led us to ponder the implications of the decisions being taken on peri-urban areas where demographic pressure is strong and with the advent of bodies aiming to oversee current practices (North, 1990). The example chosen for this study demonstrates a tendency to regulate existing practices rather than to implement proactive policies defining a preferred strategy (Evans, 1999). This approach raises the concern that such practices may become increasingly common due to the likelihood of them being accepted in the future by the authorities in charge of local urban development (the Urban Agency, the Regional Investment Centre).

⏩ Purchasing land for agricultural projects in France's Île-de-France region

The aim of this study was to decide whether the use of pre-emptive agricultural rights by local authorities is likely to boost local agriculture in large metropolitan areas like the Île-de-France (the French region where Paris is located). We worked on a database of 784 pre-emptive decisions made by SAFER[3] at the request of municipalities located in the Greater Paris area (2007–2017). With regards to the methods used, we analysed the SAFER data (factorial analysis, descriptive statistics)

2. Source: interview with the Regional Investment Centre, 2018.
3. SAFER: *Société d'aménagement foncier et d'établissement rural*, a French organization that supports projects in rural areas to serve the public interest.

and also examined qualitative data made up of in-depth interviews with a panel of 15 local authorities identified in our data as the most affected by pre-emptive choices.

The agricultural spaces in the Greater Paris area have become increasingly urbanized over the last few decades due to the need for housing, offices and the infrastructure necessary to support the development of the Parisian agglomeration. In the Île-de-France region, key players from a non-agricultural background are very active in the farmland real estate market. In fact, in 2011, some 3,260 farm properties (farmland, or mixed properties with land and farm buildings) were sold to non-agricultural buyers, while just 942 were sold to agricultural buyers (Charre et al., 2012). Since the year 2000, the market has been dominated by buyers and sellers who do not work in agriculture (incidentally, this market represents only 1% of the regional agricultural surface area; see Basciani-Funestre and Darley, 2013; Guelton, 2013). The land assets and the flow of agricultural land (the market) are therefore mainly controlled by individuals from outside the agricultural world. These individuals do not have the same aims in terms of land development as agricultural buyers or landowners. They are likely to prioritize generating a – preferably high – profit rather than maintaining and conserving agricultural practices.

In the early 1960s, France undertook a general reform of farmland policies to regulate the land market: a mechanism of authorization-to-farm was set up and local agencies (SAFERs) dedicated to farmland management and land-price monitoring were created (Boinon, 2011). Since the French rural law of 8 August 1962 was enacted, SAFERs have benefited from pre-emptive rights that allow them to intervene in property transactions and regulate the agricultural land market (Grimonprez, 2016). Pre-emptive rights can be defined as priority purchasing rights over assets intended for sale by their owner (Struillou and Hostiou, 2011). According to the French rural law, SAFERs can only exercise their pre-emptive rights when agricultural properties, the personal assets associated with them or vacant lots are transferred for valuable consideration. The role played by SAFERs is all the more important since local authorities have no pre-emptive rights over the agricultural land, countryside or woodlands under their jurisdiction the way they do over their urban spaces or future developable land (via urban pre-emptive rights).

To start with, we concentrated on the way pre-emptive decisions could be represented geographically by comparing them to data on real estate pressures. The municipalities that most often appeal to SAFERs, as part of their land monitoring and intervention agreement, are in the immediate vicinity of Paris (within a radius of 10 km to 30 km around the capital) and in sectors where the cost of agricultural land is considerably higher than average regional values (the green belt, the Yvelines region). The prices charged in these sectors are generally over 10 euros per square metre.

Given that the sale values of agricultural land are negotiated based on usual prices on the local market, they are particularly expensive, which seems to indicate a non-agricultural use (such as gardens or purchasing with a view to building) and illustrate the difficulties agricultural buyers (whether well-established or not) experience when they try to purchase land. This is, moreover, one of the first things we noticed when we analysed our data: from January 2010 to December 2017 in the Île-de-France region, 72% of the assets acquired due to pre-emptive decisions had their price revised. When revisions are granted (which systematically results in a price reduction), they significantly reduce the sale price: in half of these cases, the modified prices were 75% less than the prices indicated in the declaration of intent to transfer; in 84% of the cases, the price reduction was more 50%, and in 98% of the cases more than 25%. These figures illustrate the continuing pressure on agricultural assets in Île-de-France, where they are sold at prices that are closer to those of building lots rather than those of land meant for agricultural use or as countryside. One of the reasons for this upward trend is the preponderance in this market of players from outside the realm of agriculture.

Secondly, we focused on the characteristics of the land acquired through pre-emptive decisions, looking at its zoning on local land-use plans, its outward appearance and finally its true nature. Concerning zoning regulations, over half the pre-emptive decisions were taken in non-agricultural zones (e.g., natural zones), where derogations exist for building extensions and speculation on farmland plots is therefore more likely. Among the 784 pre-emptive decisions made between 2010 and 2017 by SAFERs at the request of different municipalities, it appears that 59% of the lots acquired via pre-emptive decisions had a surface area of between 1000 square metres and one hectare and that 32% of the lots have a surface area of under 1000 square metres. The minor scale of these acquisitions leads us to believe that such decisions were motivated more by the desire to prevent real estate speculation rather than by any grand projects on the agricultural front.

Our field surveys allowed us to identify two major motivations for invoking pre-emptive rights:

1. The main reason that municipalities exercise pre-emptive rights is to prevent real estate speculation. These municipalities tend to ask for SAFERs' help in acquiring undeveloped or partially developed agricultural land in order to sell it on to non-agricultural buyers: people looking for a second home or a private garden, or the travelling community.
2. A second reason that municipalities invoke pre-emptive rights is to support local agricultural projects (e.g., local vegetable production), often in conjunction with other policy tools (e.g., protective planning regulations). While such examples are still in the minority, they have become more common over the last few years of the decade under study.

In conclusion, both our quantitative studies on the pre-emptive agricultural decisions taken at the request of towns and the semi-structured interviews we conducted allowed us to highlight some major land-use conflicts in the rural and peri-urban areas of the Greater Paris region.

The phenomenon of scattered urbanization described in our work had been identified by preliminary interviews, but our investigation brought it into sharper focus than expected. All things considered, scattered urbanization has turned out to be the main reason local authorities intervene in the management of their agricultural land. Although an oft-cited justification, protecting and conserving agricultural land is generally a secondary consideration. In some towns, the links between the different tools that give leverage over land assets help resolve issues of scattered urbanization and support agricultural activity as part of a consistent land management strategy. Forming a partnership with a SAFER is an option that towns can choose if they wish and if they allocate resources to it. This is less often the case in small rural municipalities, which may thus find themselves powerless to deal with the issue of scattered urbanization on their agricultural land.

⏩ Conclusion

All the research presented in this chapter highlights a certain scope for action at regional level for public authorities, in order to protect farmers from the market rationales at play in terms of land use. The effects of public policies nevertheless remain limited; this is partly due to the coexistence of official institutions, customs and actual practices of private stakeholders.

In Senegal, the changes in territorial governance caused by agribusiness investments depend on the involvement of customary and legal institutions. There are numerous producers from different ethnic groups, located in a range of places and conducting various activities, and they are affected in diverse ways by these investments. Certain producers have seen their control over territorial agricultural resources diminish and have lost access to land, income and food security. Nevertheless, these same agribusinesses sometimes compensate for failing public policies by providing certain basic socioeconomic infrastructures that help increase acceptance among the population (Soullier et al., 2018). To avoid small-scale producers' loss of control of their territorial agricultural resources, agribusiness leaders and local authorities should respect customary rules, which govern the management of agricultural resources and identify mechanisms for controlling and enforcing the set of concluded agreements.

In the peri-urban area of Casablanca, the legal system allowing for the local urban schemes to be bypassed was conveniently overused by real estate promoters, in order to direct industrial development, presumably at the expense of agricultural land use. The acknowledgement of existing situations by public authorities may first lead to a lock-in effect, and later to repetitive practices by private stakeholders. A clear division of competences between the various national and subnational agencies could improve the promotion of a coherent general development design in conjunction with urban planning.

In île-de-France, various uses of the pre-emptive right are revealed. Municipalities first aim to freeze a situation, in order to avoid scattered urbanization, as a defensive strategy. Only then can local agricultural projects emerge as a result of proactive decisions.

In the context of rapid evolutions in terms of investments and use of private and public land, decisions lead to changes or adjustments of institutions and the results of some of them, like building in France and Morocco or the displacement of agro-pastoralists in Senegal, are difficult to reverse.

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Section II

Linking agricultural supply with food and nutritional needs

Chapter 3

Analysing the nutrition transition through food supply and demand: cross-perspective approaches in economics, management and nutrition

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Around the world, countries have experienced nutrition transition, first in industrialized countries and later in developing countries. Nutrition transition is known to be driven by rapid demographic, social and economic changes and results in an increasing prevalence of obesity and chronic nutrition-related diseases (Popkin, 2006a). Typically, the transition consists in a major shift from traditional to 'modern' diets, characterized by low intakes of nutrient-dense foods and high intakes of cheap, readily available, energy-dense options containing high levels of saturated fats, added sugars and refined grains. These new dietary habits lead to an imbalance between nutrient consumption and nutritional needs.

A major issue scientists must tackle is the need to characterize transition models and dynamics along with their specificities. Both industrialized and developing societies must curb nutrition transitions and identify levers to achieve food and nutrition security, in all places and for all people.

One of the most striking features of a nutrition transition is the evolution of the food supply over short periods. Globalization, increased international trade and the growing dependence on imported processed foods, cheap simple sugars and saturated fats are all contributing factors. The prices, quantities and diversity of available food products have all been affected by lower transport costs, fewer customs protections on agrifood products, and increased foreign direct investment flows in the food industry. To truly see the connection between trade and nutrition, we need to assess the dynamics of trade in food products based on their nutritional quality through a holistic analysis of the availability of all nutrients at the regional level. Such an assessment is necessary so that stakeholders can better understand the impact of food products on population health and make relevant policy decisions (Colombet et al., 2022).

Another challenge for scientists is determining appropriate methodological approaches to study how demographic and socio-economic changes influence the dynamics of nutrition transition, particularly in developing countries that are still in the midst of transition. A decomposition approach (Fortin et al., 2011) can enhance knowledge on the different roles played by demographic transition, economic development and consumption behaviour over time. Many developing countries experienced simultaneous demographic, economic, epidemiological and nutrition transitions in the 1970s and 1980s, and the effects these transitions had on each other must be understood to better guide new nutritional policies (Trinh et al., 2018a).

Finally, once the transition has been described from a retrospective point of view, attention must be focused on the levers that can be used to reverse nutrition transition through nutritional policies. These policies may include price or income-based measures or campaigns to promote traditional diets such as the Mediterranean diet, which is widely considered healthy (Belahsen and Rguibi, 2006). Assessing adherence to these traditional, healthier diets and their individual determinants, including social norms and beliefs about the benefits and costs of consuming traditional foods, can help guide public policies to encourage healthier dietary behaviours (Recchia, 2017; Aouate, 2016). The potential impact of economic policies targeting agricultural production on access to these traditional foods must also be assessed.

Nutritional transitions are complex processes involving decisions by many actors from farm to fork, and the public health consequences are significant. A multidisciplinary approach is therefore needed to explore the wide range of determinants of nutritional transitions and the potential impact of policies, as well as to address the consequences of changes in dietary patterns. For instance, while economists use models based on real data about individuals and households to make inferences (e.g., sensitivity to food prices and policy instruments), epidemiologists are concerned with the link between consumer behaviour and public health, and management scientists study the impacts of policies on the agrifood chain. Such differences in focus areas are important to understand because policies may involve demand-side instruments whose impacts can be examined by epidemiologists working with economists, while supply-side policies are best analysed by management scientists and economists. A cross-cutting, interdisciplinary approach applied to a common object of analysis, i.e., population dietary patterns, can produce a more realistic view of the causes and effects of nutrition transitions.

In this chapter, we 1) explore the role of various factors of economic and societal changes (e.g., income, urbanization, demographic transition, socio-economic changes) or dietary behaviour in dietary shifts, and 2) study supply- and demand-side levers to curb nutrition transition. These objectives have been studied in different contexts undergoing a nutrition transition: the French West Indies (Colombet et al., 2022; Colombet et al., 2020), Vietnam (Trinh et al., 2018a, 2018b) and Morocco (Recchia, 2017), where traditional dietary patterns are gradually falling out of favour among younger generations and being replaced by more modern and less healthy patterns.

⏩ Exploring nutrition transition determinants

A large body of literature in economics, public health and nutrition on the determinants of nutrition and/or health outcomes describes how policy and socio-economic factors have contributed to changes in dietary patterns, nutrition and physical activity (Hawkes, 2006; Popkin, 2006b; Schram et al., 2018). Among such factors, trade liberalization, foreign direct investment and globalization have been highlighted for their negative impacts (Kearney, 2010). For instance, lower freight costs, fewer tariff and non-tariff barriers on imports and increased foreign direct investment in the agrifood industry influence the prices of imported products, as well as the diversity, quantities and quality of available foods. Although consumers gain access to cheaper goods and more diverse products, studies have shown that lowering trade barriers and the resulting increase in international trade and globalization promote imports of obesogenic foods. Such foods are known to increase the risk of chronic diseases such as diabetes, cardiovascular diseases and cancers (Schram et al., 2018; Cuevas Garcia-Dorado et al., 2019). In certain regions of the world, this evolution is all the more worrying as their food supplies rely heavily on imports. This is the case in Mediterranean countries such as Tunisia and Morocco, which became dependent on imports of flour, sugar and vegetable oil (other than olive oil) after deciding to tackle undernutrition by subsidizing energy-dense foods (Drogué et al., 2020; Saidi and Diouri, 2017). In the French West Indies, where the local agricultural sector is highly specialized in cash crops (sugar cane and bananas), the country relies on food supplies from mainland France because it is unable to meet domestic demand, despite public support (Méjean et al., 2020).

To examine the trade-nutrition nexus in depth, Drogué et al. (2019) built the Reconcil database to align the international customs nomenclature (known as the Harmonized System – HS) that codifies products traded internationally with the CIQUAL nutritional composition table established by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES). For each HS6 code (which has been matched to one or more CIQUAL foods), the Reconcil database provides an approximation of the food's nutritional composition based on 64 nutrients. This database provides highly disaggregated data on the nutrient composition of internationally traded foods, which means these foods can be thoroughly analysed in terms of nutrition. Using this database, Colombet et al. (2022) studied the dynamics of food imports in the French West Indies (Guadeloupe and Martinique) over two decades, looking at price, nutritional quality and quantity, and types of food. The study found that animal protein, saturated fats and added sugars in processed food imports have increased dramatically over the past 20 years.

Following the work of Colombet et al. (2022), Méjean et al. (2020) also used the Reconcil database to expand the nutritional quality analysis of food imports in the five French overseas territories (La Réunion, Mayotte, French Guiana, Martinique and Guadeloupe). For these territories, the authors reported the balances of imports in plant and animal fats, complex carbohydrates, free sugar, plant and animal proteins. According to their calculations for 2015, the share of free fats, free sugar and animal protein in the imported calories per inhabitant amounted to 42% in Guadeloupe, 44% in French Guiana, 48% in Martinique, 34% in Mayotte and 33% in La Réunion. These figures are worrying: in the territories where data are available, Méjean et al. (2020) have shown that imports account for more than 90% of calorie availability in Martinique and more than 85% in La Réunion.

Thus, improving the nutritional quality of the food supply through trade seems to be a challenging problem to address through public health actions alone. In addition to considering food availability, we must also analyse how demographic and economic transitions have influenced nutritional transitions and, consequently, the food choices of the population in a given country.

Colombet et al. (2022) used both French customs data on trade at the HS6 level and the Reconcil database to empirically explore the relationships between the evolution of nutritional value of import demand over a 20-year period. They also looked at several potential determinants such as income, expansion of supermarkets, women's participation in the labour market and urbanization, all key factors of economic development. To highlight changes, the researchers used dietary markers of nutrition transition, namely animal protein, saturated fat, sugar and fibre content, and developed an econometric model of trade. Results showed that the development of food retailing, increased income and urbanization in Guadeloupe and Martinique led to rising import demand for these four nutrients. However, no link was found between women's employment and nutrient imports.

Generally, analyses of sociodemographic determinants of dietary shifts over a given period focus only on the diet composition effects that reflect the impact of changes in the studied population (e.g., urbanization, income improvement). Using recent developments in decomposition methods in economics (Fortin et al., 2011), Trinh et al. (2018b) suggest considering an additional effect – the 'structure effect' – to capture the impact of changes in consumer behaviour and eating habits in the studied population. The researchers agree with Popkin (2002) that most studies analysing dietary changes have a major limitation: they only consider changes in population composition as determinants of observed changes in dietary patterns. Existing studies do not link these changes in dietary patterns to changes in consumer behaviour. However, it is possible for consumers, with the same education or income levels, to have bought different amounts of food items at different points in time. Consumer habits may have evolved over time (reflecting, for example, a more pronounced choice for sweet foods or dairy products based on the belief that they are healthy), which can also lead to changes in dietary patterns.

Trinh et al. (2018a, 2018b) focused on the nutrition transition in Vietnam. Over the past 30 years, Vietnam has experienced sustained economic growth, resulting in demographic, epidemiological and nutritional transitions. During this period, the Vietnamese population shifted from a traditional diet (comprising locally-specific and largely seasonal coarse grains, pulses, fruits and vegetables, and some meat and fish) towards a standardized modern diet. Intakes of animal foods, fat, sugar and processed packaged foods all rose, leading to unbalanced diets that, combined with less physical activity, increased overall risks to health. Such dietary changes coexist with persistent childhood undernutrition in rural areas, as well as micronutrient deficiencies. Vietnam is now facing the triple burden of malnutrition (Pinstrup-Andersen, 2007).

Trinh et al. (2018b) analysed the change in diets of Vietnamese households between 2004 and 2014. This change has been characterized by an increase in total calorie intake per capita over the same period, not only on average but also for all the quantiles of the corresponding distribution. The shift in calorie intake from protein and fat exhibits a similar pattern. However, calorie intake from carbohydrates flattened, with increases in low and high consumption over the period, while the average intake remained stable.

On the one hand, the decomposition analysis shows that food expenditures and household size appear to be the main drivers of the composition effect, which captures the impacts of sociodemographic factors. This finding corroborates the results of many previous studies (see the systematic review done by Mayén et al., 2014). While urbanization is often noted as an important driver of dietary changes (Popkin, 2002), its shift does not seem to explain this same effect in Vietnam.

On the other hand, the decomposition analysis also shows the importance of considering the so-called 'structure' effect (i.e., the impact of changes in consumer behaviour) when studying the nutritional transition in Vietnam. Structure and composition effects move in opposite directions: structure effects always translate into decreased calorie intake, while composition effects related to the demographic and socio-economic composition of the population always translate into increased calorie intake. The total effect therefore depends on the extent of both effects individually. Remarkably, behavioural changes had almost no impact on the observed changes in fat and protein consumption over the studied period, with any impact being largely offset by the impacts of changes in population characteristics. But behavioural changes did have an important effect on carbohydrate consumption. These changes even offset the effect of changes in population composition and led to a decrease in calorie intake from carbohydrates.

Recently, Colombet et al. (2021) applied decomposition methods to investigate the contribution of demographic and socio-economic characteristics to the nutrition transition in Martinique. Health status, nutrient and food intakes deteriorated between 2003 and 2013, suggesting an ongoing nutrition transition. The demographic transition explained about half of the health status decline and marginally explained changes in dietary intake, potentially because unobserved drivers of the nutrition transition are at play, such as food price trends or retail expansion.

Levers to reverse nutrition transition from consumption to agricultural production

As previously explained, understanding the influence of political, economic and sociocultural factors on nutrition transition is essential for building relevant and context-specific strategies that achieve food and nutritional security. These strategies may simultaneously deal with food consumption, agricultural production and food chain organization.

In developing countries, fighting undernutrition remains an issue – and not a trivial one. Countries that have based their food policies on price subsidies for energy-dense foods have often succeeded in tackling undernourishment, but they have also prompted nutrition transition and import dependency, as Drogué et al. (2020) showed in Tunisia. Using innovative methodological approaches, Trinh et al. (2018a) raised the question of the relevance of income-based policy to fight undernutrition. The authors revisited the issue of estimating the relationship between calorie intake and income, often addressed in development literature (Ogundari and Abdulai, 2013), using non- and semiparametric econometrics approaches. Economic theory usually assumes that this relationship has an inverse U-shape in developing economies: calorie intake per capita increases rapidly along with income up to a given threshold, then slows down and may even stop. This income threshold provides a measure of the poverty line, i.e., the value up to which an income intervention can have a positive impact on calorie intake. The calorie intake–income relationship is estimated using each biannual wave of the Vietnam Household Living Standard Survey from 2004 to 2014. All the specifications selected for these different waves appear to be concave with a poverty threshold varying over the period. This result highlights that there is still room for income-based policies to tackle undernutrition in Vietnam, especially policies that help disadvantaged households have greater means to meet their dietary needs.

Curbing nutrition transition will mean encouraging people to eat healthier, and public policies should be directed at the people who need the most support. Studying the diet quality of a population through adherence to healthy dietary patterns is a good indicator for defining target populations. For example, following the traditional Mediterranean diet is recognized as a way to prevent non-communicable diseases (D'Innocenzo et al., 2019) and various indicators have been defined to evaluate adherence. But these indicators must be used cautiously. Recchia (2017) compared four different scores to analyse adherence to the Mediterranean diet: the transformed Mediterranean Diet Score (tMDS), the relative Mediterranean Diet Score (rMED), the Mediterranean Diet Quality Index (MDQI) and a new score, the Score based on the Mediterranean Diet Pyieramid (SPAM) as recommended in the revisited Mediterranean Pyramid reported by Bach-Faig et al. (2011). These scores are built by attributing an individual score per food group according to how much foods affect diet quality (the higher the score, the higher the diet quality). The SPAM score differs from the other scores because it includes more items. Results showed that the rate of good adherence to the Mediterranean diet was lower or higher depending on the score used, from less than a quarter (23%) for the SPAM score to just under half (48%) for the others. Older, uneducated, married woman seemed to have a better chance of adhering to the Mediterranean diet.

In addition to the above analysis, it is also interesting to know the psychosocial factors that determine adherence to a healthy diet. For instance, the traditional Mediterranean diet recommends eating large quantities of fruits and vegetables (Bach-Faig et al., 2011), whereas observed intakes are very low. Aouate (2016) studied some of the mechanisms, and specifically certain beliefs, that determine fruit and vegetable consumption using qualitative interviews (with 15 parent-child dyads) and a quantitative survey (251 parents from southern France). The results show that the pleasure dimension associated with the consumption of fruits is present in the beliefs of parents for their own consumption, but absent in the beliefs they have regarding their children's consumption. This result raises questions about the transmission of taste pleasure by parents (Aouate, 2016), and highlights the value of specific interventions that provide parents with methods to help their children enjoy the pleasure of healthy food (Marty et al., 2017). However, studying and understanding psychosocial or income factors that can encourage people to eat healthier is pointless if healthy food is inaccessible or unavailable.

Another question that arises is whether policy measures can decrease import dependence on energy-dense and obesogenic foods and improve the availability of and access to healthy foods. This question has been analysed in the Mediterranean region by Drogué et al. (2020), Le Mouël and Schmitt (2018), Ramzi (2017) and Hafidi (2017). Drogué et al. (2020) studied the impact of better adherence to nutritional recommendations for imports and concluded that simply shifting the Tunisian dietary pattern towards a healthier diet would not suffice to reduce trade dependence. Instead, a profound reorganization of the agrifood systems to restore the competitiveness of domestic production on the internal market would be necessary. Le Mouël and Schmitt (2018) drew the same conclusions regarding Mediterranean countries. More specifically, the authors suggest that yield should be improved and production factors better used to increase production capacity. This was one objective of the Green Morocco Plan (2008–2020), which aimed to bolster agricultural production and organize farmers to increase self-sufficiency, exports and farmers' income. Two analyses of the technical and economic conditions of production in the citrus fruits and durum wheat sectors were conducted in Morocco. An analysis of the various intermediaries (storage facilities, milling industry) was then performed using the structure-behaviour-performance paradigm based on 171 interviews with industry professionals (Ramzi, 2017; Hafidi, 2017). The findings showed that a supply-side policy can effectively remove some constraints on agricultural production, but cannot solve the many bottlenecks to food access. With durum wheat, in addition to the specific constraints of agricultural production (i.e., high input prices for fertilizers, pesticides and seeds), intermediaries noted insufficient financial resources to adequately manage the wheat supply chain (Ramzi, 2017). With clementines, the scarcity of irrigation water, low quality of the fruits after pest attacks and diseases, lack of market information, high quality requirements of destination markets, and limited number of importing customers were the main constraints on operators in this sector (Hafidi, 2017).

⏩ Conclusion

In this chapter, we analysed nutritional transition based on examples drawn from the scientific literature and research findings obtained as part of the INRAE GloFoodS Metaprogramme. Although this analysis is incomplete because we only discussed some of the components of nutritional transition, it does shed light on nutrition transition in different contexts, such as the French West Indies, Vietnam and Morocco. The analysis also highlights different determinants or strategies that could be leveraged to reverse the phenomenon. For example, we showed that the factors promoting nutritional transitions through demand may be related as much to the socio-economic and demographic composition of the population as to changes in people's dietary habits. We considered demand- and supply-side strategies when looking at these factors. One finding suggests that dietary characteristics of populations and psychosocial factors should be taken into account in interventions to improve nutrition. A second finding suggests that although price-support policies may have contradictory impacts, income-based policies can still be effective. But demand-side policies are not enough if access to healthy food is limited and if such policies are not accompanied by supply-side actions. This has been found to be true in Mediterranean countries, where improving diets will require a better reorganization of supply to reduce dependence on food imports and provide populations with high-quality and healthy products. As the analyses in this chapter show, a context-specific holistic approach of nutrition transition is necessary if we are to better address the resulting issues.

These case studies share a common research objective: to examine the role of socio-economic contexts of nutritional transitions and the factors determining the success of strategies to address such transitions. The case studies also share a similar approach linking the social sciences and nutrition. Finally, comparing three contexts of nutritional transitions provides important information on the conditions required for nutritional policies to succeed, when demand-side policies are not accompanied by an adequate market supply organization in the region or country.

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Chapter 4

Shocks in agricultural production: origins and impacts on commodity prices

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Price instability is recognized as a major driver of food insecurity that may have negative impacts on the social, economic and health status of many households. Since the food price spikes of 2007–2008, prices of the main food and feed crops have shown high variability in the international and local markets for almost a decade. For example, the price of maize increased by about 75% from September 2007 to May 2008. After 2015, agricultural commodity prices stabilized, but the year 2020 and the Covid-19 crisis ushered in a new period of agricultural price instability that could increase the number of people at risk of food insecurity (HLPE, 2020).

Although agricultural commodity prices are influenced by many factors (e.g., food stocks, food and feed demand, and input prices – especially fertilizer), shocks on agricultural productions are often recognized as a major driver of price volatility. Adverse environmental conditions (e.g., droughts) and the resulting decline in regional production have be shown to have greatly contributed to spikes in global food prices (Tadasse et al., 2016). The connection between production levels, agricultural commodity prices and food security has led many companies, governments and international organizations to develop forecasting systems to anticipate production shortages or, on the contrary, overproduction (see, for example, the MARS bulletins published by the European Commission[4]).

The last decade has seen a rising number of applications of machine learning, with a particular focus on anticipating agricultural production shocks (Beillouin et al., 2020; Leng and Hall, 2020; Batunacun et al., 2021; Peng et al., 2021). The reasons are multiple. First, machine learning techniques can now be more easily applied than ever before using specialized packages implemented in open source packages such as those developed in R or Python (Makowski et al., 2021). Second, large agricultural databases are becoming increasingly easily accessible, thanks in large part to the emergence of good practices in open science. Finally, mechanistic models were found to miss several major yield losses in Europe and in the US (Leng and Hall, 2020), which led scientists

4. https://ec.europa.eu/jrc/en/mars/bulletins

to look for alternative solutions. For all these reasons, different machine learning tools are now being used more often to analyse production shocks, identify their origins, and assess their consequences on food security.

Based on a brief review of the literature, we identify the main biotic and abiotic factors determining crop production shocks, propose a hierarchy for the factors with the most impact, and show that these factors are often interdependent, making crop yield forecasting rather difficult. Next, based on our own recent research projects, we show how the use of machine learning and of probabilistic models could open – in connection with the development of open access databases and new powerful algorithms – a new avenue for predicting production shocks and their impacts on agricultural prices. Lastly, we discuss the economic mechanisms that link together seasonal production forecasts and market impacts and how improving production forecasts could reduce price volatility and the risk of abrupt shifts in price trends.

⏩ Main biotic and abiotic factors responsible for production shocks

Weather-related factors

According to Food and Agriculture Organization (FAO) (2015, 2016), the number of climate-related disasters has increased worldwide since the turn of the century, generating considerable economic losses. About 332 climate-related disasters were recorded in 2004–2014, while only 149 were recorded in 1980–1990. Based on the analysis of 78 post-disaster cases, impacts in agriculture accounted for 25% of the total impact of climate-related disasters in developing countries between 2003 and 2013 (FAO, 2015, 2016). Crops tended to be mainly affected by floods (about 59% of damage and losses), followed by storms (26%) and drought (about 15%), while livestock were mostly affected by drought (>80%) (FAO, 2015, 2016).

Production shocks due to adverse climate events occur on all continents (Table 4.1). According to Lesk et al. (2016), over the period 1964–2007, drought and extreme heat substantially damaged national agricultural production across the globe and reduced cereal production by 9% to 10%. In particular, drought has been reported in many different places, with multiple impacts (PNDA, 2012). For example, the series of droughts that occurred in Kenya between 2008 and 2010 had major impacts on livestock, with a high number of deaths of domestic animals. But these droughts also affected agriculture (where output of food and industrial crops was lower than usual), the water supply and sanitation systems, the electrical sector, and the social sectors of education, health and nutrition, with negative feedback on agricultural activities (Huho and Mugalavai, 2010; PNDA, 2012). Although common in Africa, droughts also occurred frequently in other regions, such as in Australia (Hochman and Horan, 2018) and Europe (Beillouin et al., 2020). In 2018, Northern and Eastern Europe experienced multiple crop failures which were among the most severe observed in recent decades. In this region, extreme yield losses were associated with very low rainfall along with high temperatures between March and August 2018 (Beillouin et al., 2020). Several studies show that the impact of drought is likely to increase in the future with climate change in different parts of the world. In particular, Ercin et al. 2021 estimated that more than 40% of the European imports will become vulnerable to drought in the future (under the RCP6.0 scenario at the 2050 time horizon), and especially imports from Brazil, Indonesia, Vietnam, Thailand, India and Turkey.

Table 4.1. Examples of major documented crop production shocks and their main causes.

Date	Location	Main cause	Crop	Reference
1970	USA	Corn leaf blight (fungal disease)	Corn	Tatum (1971)
2002, 2006	Australia	Drought	Wheat	Hochman and Horan (2018)
2007	Mexico (Tabasco)	Flooding following severe rainfall events	Various crops, including maize, citrus, coffee, pineapple and beans	FAO (2015)
2008–2011	Kenya	Drought	Maize and beans	Hoho and Mugalavai (2010); PNDA (2012)
2010	Pakistan (Punjab)	Flooding following severe rainfall events	Cotton, sugarcane, rice, pulses, tobacco and animal fodder	FAO (2015)
2016	France	Plant diseases and excess of water	Wheat	Ben-Ari et al. (2018)
2017	Western Europe, particularly Switzerland and Germany	Frost	Orchards and vineyards	Vitasse and Rebetez (2018)
2018	North-Eastern Europe	Drought	Several major arable crops such as wheat, barley, oat, sugar beet and potato	Beillouin et al. (2020)
2019–2020	Thailand	Drought	Rice	USDA (2020)
2020	Horn of Africa, the Middle East, and South Asia	Locust outbreak	Grasslands and various arable crops	FAO locust watch website (2020)
2021	France	Frost	Orchards and vineyards	Météo-France (2021)

In addition to drought, heat stress, water excess and frost are other common causes of severe yield loss (Table 4.1). According to Zampieri et al. (2017), heat stress increased significantly in major wheat-producing areas over the period 1980–2010, especially since the mid-1990s. According to the same authors, water excess also appears to be a key issue in tropicale regions and in some regions of the mid/high latitudes; water excess seems to be an essential explanation for yield anomalies of major wheat producers such as China and India (Zampieri et al., 2017). Lobell et al. (2011) studied the overall damage caused to agricultural systems in California by extreme climatic events over a 15-year period (1993-2007), as measured by the Federal Crop Insurance Corporation in the US. Their results point to excess moisture events as the main cause of agricultural damage, followed in order by cold and heat waves. Frost can also cause severe yield losses. Vitasse and Rebetez (2018) analysed the frost damage that occurred in spring 2017 in Switzerland and Germany. They found that, in April 2017, a frost event with temperatures below −4°C followed an unusually warm period, causing earlier-than-normal plant development and severe frost damage, particularly in orchards and vineyards. A similar event characterized by a warm-cold sequence occurred in France in early spring 2021, with strong impacts on orchards and vineyards (Météo-France, 2021).

Pests and diseases

The levels of impact of pests and diseases on crop yields are highly debated in the scientific community, but there is ample evidence that pests and diseases can significantly impact crop yields. Savary et al. (2019) conducted an expert-based assessment of yield losses for five major crops worldwide, associated with 137 pathogens and pests. They found that crop pathogens and pests can substantially reduce crop yields. Compared with situations without pest and disease, the experts estimated the global yield losses at 21.5% (10.1%–28.1%) for wheat, 30% for rice (24.6%– 40.9%), 22.5% for maize (19.5%41.1%), 17.7% for potato (8.1%–21.0%), and 21.4% for soya bean (11.0%–32.4%). This study also indicates that the greatest losses mainly occur in food-deficit regions with fast-growing populations.

Although mean yield loss estimates provide interesting information on the expected level of impact of pests and diseases, it is important to note that these impacts can vary strongly across years and locations. For example, Tatum (1971) mentioned that corn leaf blight was a minor corn disease leading to less than 1% of annual loss before 1970, but suddenly became a major disease from 1970 onwards. Another example concerns desert locust incidences. The incidence of this pest can remain low over several years and then increase abruptly as soon as the weather becomes favourable to the insect's development. Thus, in 2020, swarms of desert locusts suddenly became very large and spread through the Horn of Africa, the Middle East and South Asia. They threatened large areas of pastures and crops in these regions. According to FAO, the year 2020 corresponds to the worst infestation in 25 years in Ethiopia and Somalia, in 26 years in India, and in 70 years in Kenya. The crisis has affected 23 countries over a large geographical area from Pakistan to Tanzania.

It is worth mentioning that biotic and abiotic factors are not independent. The above-mentioned spread of locust swarms in 2020 was due to an above-average rainy season in March and April that created favourable breeding conditions for locusts. Another striking example of the interdependence between weather factors and pests and diseases concerns the historical wheat yield losses observed in France in 2016. These losses were at least partly related to the atypically warm 2015 late fall and early winter, which probably led to high levels of disease incidence in spring 2016 (Ben-Ari et al., 2018).

⏩ Data-driven approaches to anticipate production shocks and assess their impact on prices

Prediction of crop yield loss

As shown above, crop yields can be impacted by many factors. Recent studies indicate that compound extremes need to be considered in addition to single climate extremes (Ben-Ari et al., 2018; Toreti et al., 2019), making the analysis of the causes of yield variation even more complex. Because of the multiple factors involved and their interactions, predicting crop yield loss is difficult and involves many research groups and private companies.

For several decades, process-based crop models incorporating detailed crop growth mechanisms were seen as very promising tools for crop yield forecasting (Wallach et al. 2019). However, it has been recently documented that these mechanistic models sometimes provided inaccurate predictions of crop yields (Lobell and Burke, 2010; Müller et al., 2016) and missed major crop failures (Ben-Ari et al., 2018). Several studies compared the performance of complex crop models with simple forecasting techniques and showed that simple classification rules and regression models based on basic climate variables – such as temperature or precipitation – often outperform complex crop models in predicting the occurrence of severe yield losses (Ben-Ari et al., 2016) and yield anomalies (Leng and Hall, 2020). In particular, none of these models anticipated the historical wheat yield loss that occurred in France in 2016 (Table 4.1), even just a few weeks before harvest (Ben-Ari et al., 2018). A major limitation of mechanistic models is that they are often difficult to parameterize from experimental data, which reduces their predictive power (Wallach, 2011). This at least partly explains their poor predictive performances (Leng and Hall, 2020).

Statistical models and supervised machine learning offer an interesting alternative to complex crop models. They are usually simple to calibrate when large datasets are available, and generally perform as well or even better than complex process-based crop models (Lobell and Burke, 2010; Ben-Ari et al., 2016). They have been increasingly used during the last decade for crop yield forecasting, in connection with the development of open access databases and powerful algorithms (Beillouin et al., 2020; Sharif et al., 2017; van Klompenburh et al., 2020). The standard procedure used to develop and test these predictive algorithms has several specificities and relies on the use of two datasets, called the training dataset and the test dataset. The training dataset is used to fit the algorithms mapping the response variable Y (e.g., crop yield) as a function of inputs X (e.g., climate variables). During the training process, the training dataset is used to calibrate the so-called hyperparameters defining the main characteristics of the algorithms considered. After this training step, the performance of the algorithms is assessed and compared using a test dataset, including data independent from those included in the training dataset. More specifically, the standard procedure includes the following steps:

1. Definition of the input variables X (sometimes called 'features') and output Y (the variable to be predicted),
2. Definition of two datasets including values of X and Y, called the training dataset and the test dataset, respectively,

3. Training of one or several algorithms predicting Y as a function of X using the training dataset,
4. Optimization of hyperparameters (if needed),
5. Test of the algorithms based on test dataset, and selection of the most accurate.

Sometimes, when no independent test dataset is available, a cross-validation technique is implemented to assess the performance of the algorithms.

An important advantage of the above procedure is that it can be easily implemented with a large diversity of datasets, inputs, outputs, and algorithms. Numerous algorithms are now used for crop yield prediction and the readers can refer to van Klompenburh et al. (2020) for a description of the most popular techniques used for crop yield forecasting such as neural networks, penalized linear regressions, random forest and support-vector machines. Concerning inputs (X), the most frequently used are related to temperature, rainfall, and soil type. Output Y is generally crop yield itself, yield anomaly (deviation from expected yield), or the probability of yield loss. Changes in cropping areas are rarely considered.

Among all these methods, penalized linear regression methods (also called regularization techniques) have recently attracted some attention for predicting crop yield. They are useful to reduce the variance of parameter estimates, especially in high dimensional spaces. These methods are based on linear regression but are subject to constraints on coefficients designed to improve the accuracy of the prediction. Sharif et al. (2017) found that two of these methods (lasso and elastic-net) outperformed classic linear regression and stepwise selection for predicting canola yields in Denmark. In a very different context, Laudien et al. (2020) used penalized regression (lasso) to select the most relevant climate input for predicting maize yields in Tanzania.

Nonparametric machine learning methods are now frequently used for crop yield prediction, in particular random forest (RF). RF generates a set of decision trees (typically several hundred), where each single tree is trained based on a bootstrapped sub-sample dataset of Y and X, with the decision rule depending on a random subset of inputs X. A detailed description of RF can be found in Makowski (2021) and recent applications of RF to crop yield forecasting are presented in Beillouin et al. (2020) and Peng et al. (2021). Compared to linear regression, RF has several advantages, as it does not make any strong assumption on the relationship between X and Y and is able to handle complex interactions. According to Leng and Hall (2020), observed maize yield anomalies in the US are very well reproduced by RF and are much more accurately predicted by this technique than with process-based crop models.

It is important to note that there is no single best algorithm that always leads to the most accurate predictions. It is thus necessary to implement the five-step procedure described above (or its variant based on cross-validation) using a range of algorithms in order to find the technique that is best suited to a given problem. With the power of modern computers, implementing this procedure does not generally require substantial computational time.

Machine learning tools have been specifically criticized for their lack of transparency and for the difficulty of using them to analyse and understand the effect of X on Y. This criticism is much less justified than before because new tools have been recently developed to visualize the simulated response of Y as a function of X. Recently, these visualization techniques (e.g., partial dependence plots, Shapley values) have been successfully applied 1) to analyse the causes of crop failures that occurred in North-Eastern Europe in 2018 (Beillouin et al., 2020), 2) to identify the drivers of grassland degradation in China (Batunacun et al., 2021), and 3) to identify the main factors of winter wheat yield variations in Europe and their evolution in time (Peng et al., 2021).

Analysis of the effect of production shocks on prices

Various models have been developed to provide crop price projections at different time steps. Most provide little insight into the effects of regional crop production variations on global prices. However, the production of several major crops, such as maize or soya bean, is concentrated in a very small number of countries. For these crops, prices are likely to be strongly influenced by the crop production and/or yield levels of a few key producers. So far, this question has not been studied in detail using data-driven techniques.

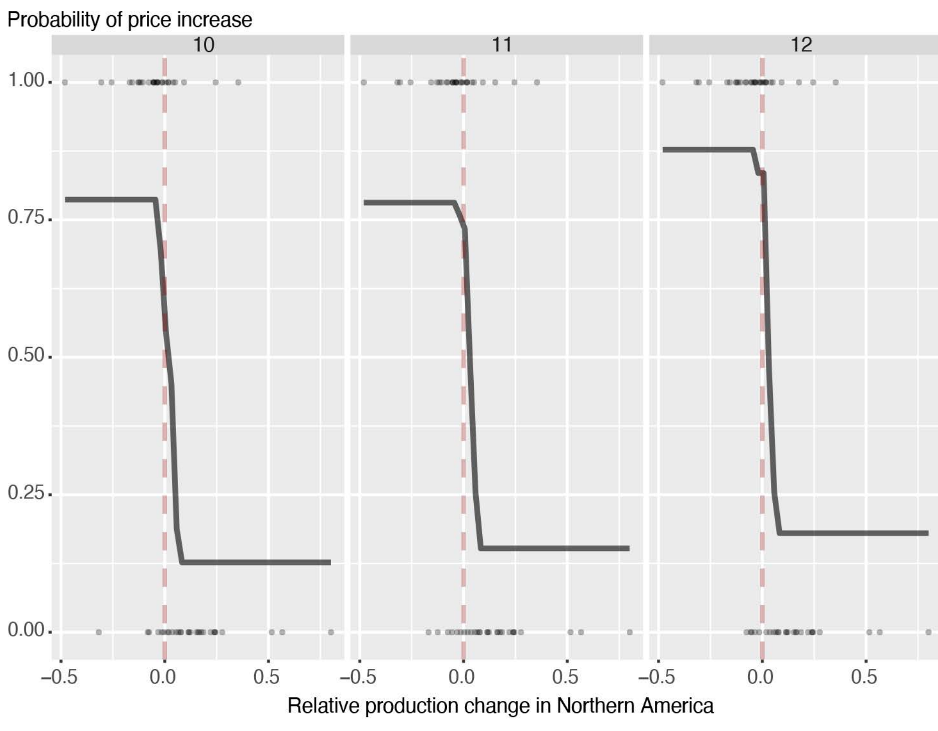

Figure 4.1. Probability of a monthly price increase of maize as a function of a relative yield change in Northern America. Source: Adapted from Zelingher et al., 2021.

The curves correspond to the mean response of probability of price increase to relative yield change in Northern America, estimated using a random forest classification algorithm. The points indicate observed variations (on the y-axis, 1=price increase, 0=price decrease) collected over 1961-2018. The three graphics report results for three months, i.e., October (10), November (11), December (12), covering the post-harvest season in Northern America. The relative yield changes (FAOstat) are expressed relatively to the previous year. The relative price changes (Maize (US), no. 2, yellow, f.o.b. US Gulf ports, World Bank database) are expressed relatively to the previous year, same months.

Recently, in order to quantify the effect of production shocks on price changes, Zelingher et al. (2021) trained and tested several statistical and machine learning models using publicly available regional yearly production data (FAOstat) and monthly price data (World Bank database). The most accurate models were used to analyse the relationships between regional maize production (or yield) and global prices, to identify the most and least influential producing regions in the global market for maize, and finally to quantify the effect of regional production (or yield) changes on global price changes.

Some of the results obtained by Zelingher et al. (2021) with RF (one of the most accurate machine learning algorithms tested in this study) are shown in Figure 4.1, where the partial dependence plots (PDPs) produced by RF are displayed. PDPs are one of the popular visualization techniques mentioned above. Here, PDPs describe the average responses of the probability of maize price increases to relative maize yield changes in Northern America. Clearly, the probability of a price increase falls below 0.5 as soon as the yield change is positive in Northern America compared to the previous year, while it reaches values well above 0.5 when the yield change is negative (i.e., yield loss in Northern America compared to the previous year). Although not shown here, the PDPs obtained with RF show much weaker trends and much flatter curves for regions other than Northern America. These results reveal that a small decrease (or increase) in maize yield in Northern America is able to inflate (or decrease) the probability of a maize price increase at the global scale, and that maize production in the other regions has a much lower influence on global price.

⏩ Information transmission in agricultural commodity markets

We have presented in the previous sections new tools that are available to predict production shocks in agriculture and their impact on price. In this section, we will show the link between the seasonal observation of these shocks and what happens on the market, detailing the mechanisms by which information about future production affects current prices.

What is the nature of information available about agricultural production? Based on the insights from the previous sections, it is any observation of natural events that correlate with production level. It could be the observation of weather (rain and temperature), pest pressure, or some remote sensing measurements (e.g., Normalized Difference Vegetation Index). Given the strategic importance of agriculture, national statistical agencies regularly release production forecasts and update them with new information. This is at least the case for the main staple crops for which the International Grains Council, the US Department of Agriculture (USDA), and the Agricultural Market Information System each provides monthly production forecasts. The history of these production forecasts associated with contemporary market reactions inform us about the way information affects agricultural commodity markets.

How can information about a coming harvest affect current prices? This is where the structure of markets matters to understand the role of production forecasts. Production forecasts are about the level of future production, while the current price should clear the market given the currently available quantities, not given future quantities. Forecasts can have an effect on current prices only if prices are linked together through time, which is not the case for every agricultural product. But this is the case for many field crops because they tend to be storable, sometimes after processing (e.g., sugar beet is storable in the form of refined sugar). Storage creates a link between market conditions today and future market conditions. If actors storing a commodity learn that the coming harvest will be smaller than expected, they will expect higher prices in the future and hold onto their stocks. If all actors storing the commodity do the same, this will increase prices in the market now because of the reduced supply.

This seems to require those holding stocks to have strong forecasting abilities, since they must convert a prediction about quantities into a prediction about prices. In practice, many storable crops are also traded on futures markets. So, futures markets would be the place where information about future production is translated into information about future price. There is ample evidence that, on the days the USDA releases new production forecasts, futures markets adjust strongly in the direction of the surprise (Karali et al., 2019): prices increase if the production forecast is lower than expected by the market and vice versa. This shows that, when they are present, futures markets are key to aggregate the various sources of information and make them consistent through a price.

Information on future production has an effect on prices (futures and spot) but it has also an effect on quantities, leading to changes in the way resources are allocated in the market. We have mentioned storage levels that adjust to the new environment, but many other decisions also adjust, such as decisions on production of competing crops, consumption decisions and import and export levels. Overall, these adjustments help align agents' behaviour with incoming market scarcity. If the harvest is predicted to be small, spot and futures prices will increase, driving up storage and production if possible (for example in the other hemisphere) and driving down current uses, which may help avoid a price spike.

Accounting for all these adjustments is empirically difficult, especially since, for many crops, harvests are globally spread across months and countries. To circumvent this difficulty, Gouel (2020) conducted a modelling study focusing on soya bean, which has a very concentrated production, with more than 80% of world production coming from Argentina, Brazil, and the United States. Since the 1980s, the USDA provides soya bean production forecasts for Argentina and Brazil in addition to the US forecasts. This allows agents to assess the amount of information about the coming harvest provided each month. This is illustrated in Figure 4.2. If the future harvest is assumed to be represented by a continuous distribution because of the uncertainty related to the conditions during the growing seasons, each passing month allows the collection of information about the growing conditions, reduces uncertainty, and narrows the statistical distribution. So, the closer one is to the harvest, the more precise the estimation of its level.

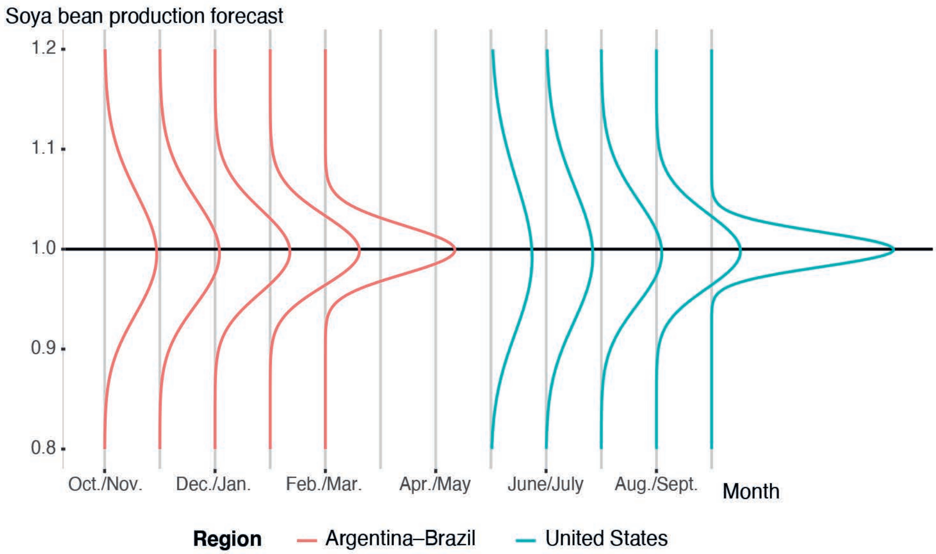

Figure 4.2. Evolution of soya bean production forecasts across the seasons. Based on data from Gouel (2020).

The curves correspond to the densities of the production forecast, with the average production normalized to 1 for all periods. The standard error of each density is calculated from time series of USDA production forecasts. In this simplified representation, harvests are assumed to take place in Mar/Apr in Argentina-Brazil and in Oct/Nov in the US.

Gouel (2020) also builds a model of the global soya bean market to assess the effects of this seasonal information. He shows that seasonal forecasts have complex effects on crop price volatility. Overall, these forecasts tend to decrease price volatility, because they allow agents to better prepare themselves for the new market conditions. But they also shift price volatility earlier in the season. If harvests were only observed when realized, prices would be very volatile during the harvest period. However, with good seasonal forecasts, as available for some major field crops in the US, the harvest can be relatively well known before it occurs so prices are not particularly volatile at harvest. They are volatile when new information arrives, hence during the growing season. But the growing season is also the season when stocks are at their lowest (they decrease from one harvest to the next). Stocks are useful to absorb the effects of shocks, but when stocks are low, the market is more sensitive to shocks. Moving information flows from the harvest season to the growing season implies shifting them to the period when stocks are at their lowest. In short, seasonal forecasts decrease price volatility on average, but they also increase it during the growing season because it is a period of large sensitivity to shocks. In addition, the possibility of adjusting stocks early in the season based on seasonal forecasts reduces the need to carry large inter-seasonal stocks.

⏩ Conclusions

The quantification of production shocks in agriculture and their consequences has recently made significant progress, thanks to a combination of new data and new statistical approaches based on machine learning. This is important because few countries can currently afford the costs of the field surveys that are the basis of production forecasts in the US. These new techniques are inexpensive to implement and scalable, so they could be more easily applied in countries with limited resources.

Better seasonal crop forecasts are important for food security and price volatility, because they allow authorities and market players to adjust in advance for harvest failures and price changes. It is common for developing countries to contemplate food security policies involving grain storage, which can be costly. Since public information during the growing season is effective in reducing the occurrence of price spikes without increasing stock levels, the provision of such information should be considered a valuable strategy.

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Chapter 5

Food diets and land-use change at a global scale: the key role of modelling frameworks

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Changes in food diets all over the world are of crucial importance regarding the environmental impact of agriculture at a global scale. Combined with changes in world population, they significantly affect the global food demand and, in turn, the global supply of agricultural products as well as competition for resources used in agricultural production.

The consequences of food diet changes at a global scale have been extensively studied. Some studies focus on impacts on land-use change (Paillard et al., 2011; Erb et al., 2016; Mora et al., 2020) and others on their intensification effects (Brunelle et al., 2014). Impacts of diet change on greenhouse gas (GHG) emissions have also attracted a lot of attention (e.g., among many others, Stehfest et al., 2009; Hedenus et al., 2014; Searchinger et al., 2019; Clark et al., 2020). The effects on biodiversity have also been investigated (Henry et al., 2019). Beyond environmental impacts, some authors have emphasized how and to what extent changes in diets could affect food prices (Stevanović et al., 2017) or human health (Willett et al., 2019).

These studies show the key role of food diets as regards the environmental impacts of agriculture. They also point out the sensitivity of environmental impacts to the share of animal-based foods (especially ruminant meat) in diets. Furthermore, some studies emphasize the positive effects, from both an environmental and human health perspective, of a global transition towards healthier diets: more balanced and more diversified, with a higher proportion of pulses, fruits and vegetables all over the world, and a lower proportion of animal-based foods, sugar and sweeteners, and vegetable oils, at least in developed and emerging countries.

While all existing studies do agree on the close link between food diets and the environmental footprint of agriculture, they report very different results on the extent of the environmental impacts at the global scale (e.g., Le Mouël and Forslund, 2017, on land-use change impacts; Prudhomme et al., 2020a, on GHG emissions). Part of these divergences may be due to differences in scenarios, but the models used are also a potential source of divergent results. This is especially clear when comparing the environmental (and economic) impacts of a same set of scenarios (namely the SSP-RCP scenarios[5]) that are simulated with different integrated assessment models (IAMs) (e.g., Popp et al., 2017). Of course, these models use different data and parameters that may produce different results. However, they also adopt different modelling approaches, which matter in significant ways (e.g., Prudhomme et al., 2020a). Unfortunately, when several IAMs are used to simulate the same scenarios, the role of the modelling approach as regards the obtained results is often mentioned but never actually explained. Instead, nearly all studies directly focus on average or median values, neglecting a large part of the overall information generated by the set of used models. A notable exception is von Lampe et al. (2014) where differences between models are exposed and divergence in results is analysed.

In this study, we advocate for more transparency when reporting simulation results obtained from several different models but with the same scenarios. We argue that focusing on average or median values contributes to hiding the fragility and uncertainty of simulation results. Meanwhile, pointing out the main mechanisms at stake in the various models and emphasizing the extent to which these mechanisms explain the divergence in results would likely help to a better understanding and interpretation of results and contribute to clarify the scientific debates.

For that purpose, we focus on the land-use change impacts of food diet change. Our objective is to show how and to what extent the modelling framework may affect results. More specifically, we are interested in pointing out the main mechanisms in various models, which are responsible for most observed divergences in results. Thus, we simulate four contrasted diets with three models based on contrasting modelling frameworks.

We use few models (fewer than other similar exercises, e.g., von Lampe et al., 2014[6]), but we consider a non-economic model (a biomass balance model), which enlarges the spectrum of the modelling frameworks considered. Moreover, working with few models makes it easier to harmonize the scenarios' assumptions across models, in order to isolate the mechanisms leading to divergent results.

⏩ Three contrasted modelling frameworks

We consider three models: a biomass balance model, GlobAgri, and two partial equilibrium market and trade models: MATSIM-LUCA (Market And Trade SIMulation model for Land-Use Change Analysis) and NLU (Nexus Land Use).

5. As part of the Intergovernmental Panel on Climate Change (IPCC) work, the climate change research community has proposed a set of socio-economic scenarios (the SSP: Shared Socio-economic Pathways) that are combined with a set of climatic scenarios (the RCP: Representative Concentration Pathways).
6. von Lampe et al. (2014) considered ten global economic or integrated assessment models, with different characteristics, functioning, spatial resolutions and levels of disaggregation of the agricultural sectors: six computable general equilibrium models (AIM, ENVISAGE; EPPA, FARM, GTEM, MAGNET) and four partial equilibrium models (GLOBIOM, IMPACT, MagPIE, GCAM).

A biomass balance model: GlobAgri

GlobAgri is a biomass balance model that uses FAOStat data and other complementary data for livestock, nitrogen balance and GHG emissions. Such models ensure that resources (domestic production and imports) equal utilization (food, feed, other uses and exports) for each product in each country or group of countries (hereafter referred to as 'regions'). In GlobAgri, for each product, imports are a linear function of total domestic use and exports are a constant share of the corresponding world market. Domestic feed use is a linear function of the domestic production of the various animal products.

In GlobAgri, a change in food diet impacts total domestic use, which in turn affects trade and production. In the case of animal products, a change in production impacts feed use of plant products, which adds to food use that affects total domestic use. Domestic production changes result in cropland and pastureland area adjustments through given crop and pasture yields[7]. GlobAgri also allows for projecting the nitrogen balance and estimating GHG emissions. This modelling framework has been used in several foresight studies on agricultural and food systems change up to 2050 at a global level (Le Mouël et al., 2018a) or in some world regions (Le Mouël et al., 2015), as well as on the evolution of GHG emissions from agriculture (Searchinger et al., 2019).

The version of GlobAgri used here is based on the one described in Le Mouël et al. (2018b), which was used in the Agrimonde-Terra Foresight Study (Le Mouël et al., 2018a). The reference year is the 2007–2009 average (denoted '2008' for simplicity reasons). The world is divided into 14 world regions and 33 agrifood product aggregates are considered. We have called the generic version of the model GlobAgri and the specific version used here GlobAgri-DietsAgT.

Two economic models: MATSIM and NLU

MATSIM-LUCA is a partial equilibrium model. In MATSIM, as is usual in most agricultural markets and trade models, a price-responsive supply function faces several price-responsive (food, feed and other uses) demand functions, for each product in each region. As a result, the demand for food (diets), notably, is endogenous and consumption varies according to relative price changes on markets. Furthermore, production technologies and markets for land and for other inputs are explicitly modelled in MATSIM. They rely on Constant Elasticity of Substitution and Constant Elasticity of Transformation functions. In other words, crop yields are endogenous and price-responsive: a change in the price of a crop modifies the optimal mix of land and other inputs for producing this crop. In turn, the prices of land and other inputs adjust, which affect the production of other crops, etc. The mechanism is similar for livestock production: a change in the price of an animal product modifies the optimal mix of the different feeds in the ration (grass, feed crops and products) in the corresponding livestock production systems, the prices of feeds adjust, modifying the composition of the ration in other livestock systems, etc. Finally, as for crops, livestock productivity

7. In GlobAgri, constraints on land can be taken into account through changes in trade parameters. In the version we are using here, those constraints are not activated, so areas can adjust freely.

is endogenous and responsive to prices. The main difference relative to crops lies in the yield of grass on pastureland: in MATSIM, as in GlobAgri-DietsAgT, grass yield is exogenous and does not respond to prices.

Trade is modelled according to the Integrated World Market (IWM) approach with net exports deduced from domestic supply and demand functions. At equilibrium, for each product, the world price balances the net export functions from all regions. Trade policies are modelled via price-transmission equations from world to domestic prices.

The reference year is 2009 and the projection horizon is 2030. The model considers 17 world regions, and more than 40 agricultural and biofuel products. MATSIM-LUCA is described thoroughly by Levert et al. (2017). The model has contributed to a series of research work that assesses the impacts of biofuel development in France and in the European Union (Forslund et al., 2013) and evaluates the environmental impacts of France's dairy policy (Salou et al., 2019).

NLU (Nexus Land Use) is also a partial equilibrium model of world agricultural markets and trade. The functioning of the model differs from MATSIM in several aspects. First, the demand for food is exogenous, as is the absolute level of trade in monogastric animal products. Second, the specification of supply in crop and livestock sectors is different, as NLU is based on two main intensification processes in agriculture, namely the substitution between 1) land and fertilizers in the crop sector and 2) grass, food crops, residues and fodder in the livestock sector. Total production cost per region is minimized under a supply-use equilibrium for food markets (energy-equivalent quantities). The model considers several land classes, which are obtained from potential yields simulated with the crop model LPJmL (Lund-Potsdam-Jena managed Land), taking into account heterogeneous pedoclimatic conditions. Deforestation rates are exogenous (i.e., exogenous land area in or out of the agricultural sector in each region). The yield of each crop in each land class is a non-linear function of chemical inputs use, with an asymptote equal to the potential yield in the land class. The supply of each animal product for each livestock production system is a linear function of animal feed consumption. Therefore, the productivity of each livestock sector at the regional scale adjusts endogenously through both relocation of production on different land classes and shifts between production systems (notably mixed and pastoral systems in ruminant sectors). A major difference with MATSIM is the endogeneity of grass yield on pastureland.

A detailed description of the NLU model can be found in Souty et al. (2012). The calibration of the NLU model is detailed in Souty et al. (2013). The model considers 12 world regions and five agricultural and food products. NLU has been used to analyse the consequences of changes in fertilizer prices (Brunelle et al., 2015) at the global scale. The model has also contributed to climate policy assessments (Prudhomme et al., 2020b), as well as to the evaluation of the impacts of legume production development in Europe (Prudhomme et al., 2020a).

Three contrasted modelling approaches

Although the three models do share similarities, their modelling frameworks differ significantly in several ways. GlobAgri does not allow for substitution between products, which makes the production, consumption and trade patterns rather rigid in this model. These patterns are more flexible in MATSIM due to the price responsiveness of supply, demand and trade. In NLU, they are flexible as well but to a lesser extent since food demand is exogenous and traded quantities are constant for some products. Finally, the three models differ significantly in their supply modelling approach, which makes crop yields and livestock productivity more or less responsive to changes in prices. In GlobAgri, changes in crop yields and livestock productivity are exogenous: they are set outside the model as part of the simulated scenario. In MATSIM and NLU crop yields and livestock productivity are endogenous and responsive to prices, with the exception of grass yields in MATSIM which are set exogenously. In NLU the response function of yield to chemical inputs involve biotechnical constraints, which limit the extent of crop yield adjustments to prices changes, relative to MATSIM.

⏩ Simulated scenarios

Diet change assumptions

We consider four diet scenarios leading to contrasting diets in 2050. Three scenarios (Animp, Ultrap, Healthy) come from the Agrimonde-Terra foresight (Le Mouël et al., 2018a) and the fourth (FAO) is a business-as-usual (BAU) scenario.

The FAO scenario assumes that current regional trends in food energy content and diet composition will continue until 2050. Thus, in the FAO scenario, food energy per capita is assumed to stabilize in developed regions and to increase in emerging and developing regions. Per capita intakes of animal products stagnate in developed regions and rise in emerging and developing regions. In all regions, there is an increasing substitution from ruminant to monogastric meat. A general increase in per capita intake of vegetable oils and sugar and sweeteners takes place all over the world. The FAO scenario relies on FAO's projections (Alexandratos and Bruinsma 2012) for GlobAgri-DietsAgt and NLU, and on the OECD-FAO World Agricultural Outlook (2014) for MATSIM.[8]

The Animp scenario uses the Agrimonde-Terra hypothesis 'Transition to diets based on animal products and urban style of eating'. Changes in diets are similar to those described for the FAO scenario, but they are much stronger in emerging and developing regions. In Animp, per capita intake of animal products, especially meat, strongly increases.

The Ultrap scenario relies on the Agrimonde-Terra hypothesis 'Transition to diets based on ultra-processed foods and globalized value chains'. Here again, changes in diets are similar to those of the FAO scenario, but with a significant shift to ultra-processed products in all regions of the world. As a result, the Ultrap diets in 2050 are particularly rich in vegetable oils, sugar and sweeteners, salt and poultry meat (which was substituted for the majority of ruminant meat) in all regions. The rise

8. OECD-FAO projections (World Agricultural Outlook 2014) cover the 2014–2023 period. They were extended linearly until 2030 for the model's purpose.

in the per capita intake of animal products, similar to the one observed in the FAO scenario, is significantly lower than in Animp.

The Healthy scenario adopts the Agrimonde-Terra hypothesis 'Healthy diets based on food diversity'. Here, a profound transition of food systems is taking place towards more balanced, more diversified and therefore healthier diets. Per capita food energy intake decreases in developed regions, decreases or stagnates in emerging regions and stagnates or increases (up to nutritional recommendations) in developing regions. Per capita intake of animal products decreases in all regions, except for in India and Sub-Saharan Africa, where they are assumed to rise to recommended levels. Per capita intake of vegetable oils, sugar and sweeteners and salt falls strongly, while that for fruits and vegetables, coarse grains and pulses increases significantly.

Details on the quantitative assumptions for the three Agrimonde-Terra diets are provided in Le Mouël et al. (2018a).

Assumptions on other variables

GlobAgri-DietsAgT and NLU use FAO's projections for 2050 as a basis for the assumed changes in crop yields (except dynamic crops), cropping intensities and bioenergy consumption. In MATSIM, assumptions on crop yields and other uses (including bioenergy consumption) are based on OECD-FAO's projections (World Agricultural Outlook, 2014). The three models use rather similar projections of livestock efficiencies (based on Bouwman et al., 2005).

Assumptions on additional variables are required for NLU. Rates of deforestation and reforestation up to 2050 are based on past trends, with an assumed stop in reforestation in 2020. The changes in the input use efficiency parameter are consistent with data on nitrogen use from Alexandratos and Bruinsma (2012). Potential yields for crops are assumed to be constant over the period.

Finally, several adjustments were made in NLU and MATSIM in order to be able to compare the three models' outputs. Since the base year is 2001 in NLU, diets were first projected until 2010, according to FAO's projections, for consistency with the reference years of the two other models. In MATSIM, simulation results were adjusted linearly from 2030 to 2050, and then proportionally to fit with the larger cropland area accounted for in GlobAgri-DietsAgT and NLU.

⏩ Results

The four diet scenarios induce global agricultural land expansion from the reference year up to 2050 (Tables 5.2 and 5.3). However, the extent of the expansion varies widely across scenarios, emphasizing the significant impact of food diets on land-use change, and across models, pointing out the key role of the modelling approach. We first analyse and compare results emphasizing the role of the scenarios (diet change) using the results obtained from GlobAgri-DietsAgT, which are easier to understand. In a second phase, we expand the analysis to the role of the models.

Impacts of food diet changes on the world agricultural land use: comparison of scenarios

As shown in Tables 5.1 and 5.2, in GlobAgri-DietsAgT, the extent of agricultural land area expansion at the world scale depends closely on both the food energy content and the animal-based food share in diets. Thus, the Animp scenario, which involves the richest diets in terms of food energy content and animal-based foods, leads to the largest world expansion of cropland (+406 million ha) and pastureland (+4055 million ha). The FAO scenario induces a large agricultural land expansion as well, but it is significantly lower than the previous scenario (+189 million ha for cropland, +1995 million ha for pastureland) as the BAU trends lead to diets that are similar in terms of food energy content but significantly less rich in terms of animal-based foods. Ultrap diets are rather close to FAO diets in terms of food energy content and share of animal-based foods, but they are significantly richer in vegetable oils, sugar and sweeteners and poultry, three product categories that are amongst the highest performance in terms of kilocalories produced per hectare. Unsurprisingly, the Ultrap scenario implies the smallest agricultural land expansion, with a decrease in cropland area (–22 million ha) and a limited expansion of pastureland (+243 million ha).

Finally, the medium range of agricultural land expansion induced by the Healthy scenario (+101 million ha for cropland and +608 million ha for pastureland) results from two opposite effects. As diets are less rich in food energy and in animal-based foods, on a world average, this scenario leads to lower agricultural land expansion at the global scale. However, for some developing countries in Africa and for India, the Healthy diet is richer in food energy and in animal-based foods than the other diets. Since these regions are highly populated, with an expected strong demographic growth, and rather underperforming in terms of agricultural productivity, this diet has a significant positive impact on world agricultural land expansion.

Table 5.1. Change in world cropland area (from the reference year to 2050, in million hectares).

Model Scenario	GlobAgri-DietsAgT	MATSIM	NLU
Animp	+406	+76	+634
FAO	+189	+113	+436
Healthy	+101	+148	+75
Ultrap	–22	+146	+290

Table 5.2. Change in world pastureland area (from the reference year to 2050, in million hectares).

Model Scenario	GlobAgri-DietsAgT	MATSIM	NLU
Animp	+4055	+430	–327
FAO	+1995	+350	–129
Healthy	+608	+291	+230
Ultrap	+243	+343	+17

Impacts of food diet changes on the world agricultural land use: intercomparison of models

Tables 5.1 and 5.2 show that the range of outcomes of world agricultural land expansion is significantly reduced when the scenarios are simulated with MATSIM relative to GlobAgri-DietsAgT. This is due to price smoothing and product substitution mechanisms operating in economic models. Such mechanisms contribute to guiding consumption towards the cheapest products (through product substitution including via imports) and to guiding production towards the least costly products (through product substitution, adjustments in input use and location substitution via exports). The logical result is that, for the same quantities consumed, the required world agricultural land area is lower with an economic model than with a biomass balance model. This is particularly true for MATSIM, where crop yields and livestock productivity are endogenous and land and other input markets are modelled explicitly, making these adjustment levers particularly sensitive in simulations.

These levers are at the root of the observed change in the ranking of scenarios when comparing cropland expansion obtained from GlobAgri-DietsAgT and MATSIM (Tables 5.1 and 5.2). For instance, Animp leads to the largest world cropland expansion with GlobAgri-DietsAgT and the smallest with MATSIM. With the latter, the strong increase in food demand and especially in animal-based foods exacerbates competition for land, which results in a significant rise in land prices in all regions. Farmers respond by intensifying their systems and increasing yields (per hectare yields of both crops and livestock). Such an increase alleviates the need to expand cropland. The same mechanism operates in Ultrap but, in this case, although crop yields increase, significant cropland expansion remains necessary to address the strong rise in food demand. The reverse mechanism explains why, with MATSIM, the Healthy diet induces a rather large cropland expansion: the moderate increase in food demand makes land prices increase less and crop yields rise more moderately (Table 5.3).

Table 5.3. Annual growth rates (%) of per hectare yield on cropland and pastureland per scenario according the three models (world average, from the reference year to 2050[1]).

Model	GlobAgri-DietsAgT		MATSIM		NLU	
Scenario	**Cropland**	**Pastureland**	**Cropland**	**Pastureland**	**Cropland**	**Pastureland**
Animp	+0.97	−0.07	+1.5	+0.7	+0.34	+1.29
FAO	+0.97	−0.07	+1.1	+0.7	+0.35	+0.82
Healthy	+0.97	−0.02	+0.5	+0.7	+0.38	+0.14
Ultrap	+0.97	+0.26	+1.4	+0.7	+0.36	+0.35

[1] Cropland yield world average in 2050 was computed using the production pattern from 2010 to isolate the ‘pure’ yield effect.

Finally, the absence of such a mechanism for pastureland, where grass yield is exogenous, explains that the ranking of scenarios is the same with GlobAgri-DietsAgT and MATSIM, when dealing with world pastureland expansion. The difference in the extent of expansion between both models can largely be attributed to the final location of livestock productions, which in MATSIM easily move to regions with higher yields and livestock productivity through flexible trade modelling, compared to the very rigid representation of trade in GlobAgri-DietsAgT.

NLU's results also differ from those of the other models. The key mechanism in NLU is the intensification/extensification process of agricultural production described previously for MATSIM, but in NLU grass yield is endogenous, while the supply and the trade modelling frameworks contribute to limit the range of crop yields adjustments. Therefore, average yield increases are lower for cropland in NLU than in MATSIM whatever the scenario, while they are higher for pastureland for two scenarios (Animp and FAO) (Table 5.3). Hence, just as Animp and Healthy were the scenarios using the least and the most cropland, respectively, with MATSIM (following the price responsiveness of crop yields in this model), it is not surprising that the same scenarios use the least and the most pastureland, respectively, with NLU, due to the price responsiveness of pastureland productivity in this model. For example, in the Animp scenario, as food demand increases, especially for ruminant products, the share of ruminant mixed systems rises to the detriment of pastoral systems. Because mixed systems' feed rations are richer in concentrate feed, and since grazing intensity in mixed systems are higher than in pastoral systems, the ruminant sectors as a whole need less pastureland areas and more cropland areas. This mechanism produces much lower impacts on pastureland areas in Ultrap since the food diet in this scenario involves a strong shift from ruminant meat to monogastric meat. One may notice that in NLU, the above-described effects are exacerbated by assumptions on deforestation, which imply a constant total agricultural land area (cropland plus pastureland) in all scenarios. Consequently, in NLU, diet changes lead to a reduction in pastureland area when the demand for ruminant products increases. This is in contrast with results from both other models.

The difference in the intensification/extensification process between MATSIM and NLU – where the former prioritizes the crop yields lever and the latter emphasizes the ruminant livestock productivity lever – is also reflected in their respective results in terms of world price changes (Table 5.4). Whatever the scenario, world price changes are lower for crops with MATSIM and, most often, lower for ruminant products with NLU.

Table 5.4. Change (%) in world market price indices of crop and livestock products, per scenario according to MATSIM and NLU models (weighted averages over product categories, from the reference year to 2050).

Model	MATSIM			NLU[1]	
Scenario	Crops	Monogast.	Ruminants (incl. milk and dairy)	Crops	Ruminants (incl. milk and dairy)
Animp	+1.5	+2.0	+2.8	+3.1	+1.7
FAO	+0.4	+1.1	+1.8	+2.4	+1.6
Healthy	−0.3	+0.5	+1.1	+1.0	+1.2
Ultrap	+1.0	+1.0	+1.9	+1.8	+1.4

[1] NLU assumes fixed traded quantities of monogastric animal products. Therefore, there are no world market prices for these products in the model.

⏩ Conclusion

Our analysis shows that, regardless of the modelling approach, food diets and their future evolution across all world regions have significant impacts on agricultural land use and the extent of agricultural land area expansion at the global scale. We also point out that, whatever the food diet scenario, the modelling approach significantly affects simulation results.

Biomass balance models, such as GlobAgri-DietsAgT, can only adjust quantities. They predict very contrasting, and for some scenarios very large, adjustments of world cropland and pastureland areas in response to changing patterns of food diets all over the world. Economic models, such as MATSIM and NLU, can adjust both quantities and prices, and allow for product substitution and intensification/extensification of production systems. Therefore, the quantity-price smoothing mechanism in such models mitigates adjustments of world cropland and pastureland areas to changes in food diets.

Biomass balance models likely overestimate land-use changes, at least when simulated scenarios are not designed with a global perspective and are instead only differentiated on a single dimension, as is the case here (food diets). Nevertheless, they are simple and very didactic, which makes them useful in some contexts (Mora et al., 2020).

As far as economic models are concerned, our analysis clearly shows the crucial role of the intensification/extensification process involved in models with regard to the land-use change impacts of scenarios. It is worth noting that this process, included in both MATSIM and NLU, produces very different results in terms of agricultural land expansion at the global level. This is mainly due to different modelling options retained for crop yield adjustment (more flexible in MATSIM) and pastureland productivity adjustment (more flexible in NLU). In this regard, our study suggests that pointing out the main mechanisms at stake in the various models and emphasizing the extent to which these mechanisms explain the observed divergence in results, should become a systematic step when reporting simulation results of the same scenarios obtained from different models. This would certainly contribute to facilitating the understanding of results, highlight their fragility and uncertainty and, in turn, clarify scientific debates.

Our study also shows that performing such analysis can shed light on crucial issues in scenarios: the future evolution of crop and grass yields as well as livestock productivity in our case. For crop and grass yields, we note that, given the same diet changes, their levels in 2050 are different in GlobAgri-DietsAgT and as simulated by MATSIM and NLU. Therefore, in addition to making yield levels more transparent when analysing results (not very frequent when global scenarios are compared), our analysis shows that interdisciplinary dialogue on plausible crop and grass yield changes, either used as model inputs or simulated by models, would be fruitful and even necessary. Of course, the same remark also applies to livestock productivity and all other technical key variables/parameters whatever the model.

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Section III

From agroecological innovations to dietary diversity

Chapter 6

Valuing the roles of women in food security through a gender lens: a cross-cutting analysis in Senegal and Nicaragua

Sandrine Fréguin-Gresh, Danièle Clavel, Hélène Guétat-Bernard, Geneviève Cortès, Valentina Banoviez-Urrutia, Sandrine Dury

Food security and nutrition (FSN) is a key issue in rural areas in the Global South, where the majority of the world's undernourished people live (FAO et al., 2020). Gender equality and women's empowerment are one of the major Sustainable Development Goals for 2030 because women are newly recognized as key players to combat malnutrition in all its forms, from food production to consumption (DG DEVCO et al., 2019; FAO, European Union, 2017). While many studies underline the need to enhance nutrition and food security, few of them highlight the role of women in improving the FSN of their families. Women diversify diets and maintain skills and traditional knowledge by preparing meals that are nutritious, safe and culturally relevant (Keatinge et al., 2011) and which also preserve biodiversity (CDB, 2015). Recognizing the role of women in FSN is crucial, but at the same time, it should be also considered as one part of all the other activities they perform.

FSN is often assessed according to the availability of farm production and its measurement, based on indicators that are mostly conceived for the household level (such as the Household Food Insecurity Access Scale). But these metrics ignore the individual situations of household members. Moreover, many studies consider that the nuclear family and the farm overlap: the head of the household, usually a male, is thus the decision maker (De Iulio et al., 2015). However, those types of metrics are simplistic (Gastellu, 1980), as most farm households have other income-generating activities that can also be multi-situated (Fréguin-Gresh et al., 2015). In addition, household members usually play different roles in terms of FSN (Coates et al., 2018). Thus, few studies document the role of gender in farming and food systems (Guétat-Bernard and Ndami, 2019; Stephens et al., 2018), probably because the contribution of women in the households' activity portfolio are mostly (and incorrectly) confined to the domestic economy. However, women contribute substantially to food-related activities, even if they do not always have the power to make decisions or to take action.

This chapter, based on two case studies, aims to answer several questions: What roles do women play in ensuring access to food for their households? How are these roles maintained and reconfigured over time? Given that relations of domination historically shape gender relations, how do women negotiate spaces for action or recognition?

This chapter analyses the results of two projects undertaken between 2015 and 2019 in Senegal and in Nicaragua. The projects examined the roles of women in FSN and the functioning of 'the kitchen', as a particular economic and political space. The first section gives the scientific positioning that guides the comparison, the second part outlines the analytical framework that underpin the comparison of the projects' findings and the third section then gives contextualized evidence of gender inequalities related to the underestimation of their importance in household FSN.

⏩ Reconsidering women's contributions to household FSN

This positioning connects three elements: 1) the recognition of women's work in the two interrelated productive spaces (especially the farm) and domestic spaces; 2) 'the kitchen', as a place of power and knowledge; and 3) the tensions, for women, between assigned roles and their search for autonomy or resistance.

Recognizing the invisibility of women's work

In family farming, work is not founded on labour relations, but on an obligation structured by kinship and marriage alliances (Barthez, 1984). These family bonds link the family to its farm heritage and resources (Ancey and Fréguin-Gresh, 2015). Moreover, as shown by the feminist intersectional perspective of connected categories such as age, gender, social status and birth order (Crenshaw, 1989), household members are unequal. Each individual depends on the institutions that structure each society, especially the family, while connecting with other hierarchies such as the position of the household in the society (family with or without land, formal or informal rights and status linked to ethnicity).

Throughout the history of men's domination of women, labour and access to resources have always been socio-gendered. The analysis of women's contributions to productive spaces needs to be repositioned within specific sociohistorical and cultural matrices. The reasons for this permanent blindness to gender were enunciated by the materialist feminist research, which calls for the denunciation of gender asymmetries, the invisibility of women's roles in domestic production (Delphy, 1970), and the connection of productive and domestic spaces. Agricultural modernization, coupled with capitalism and patriarchy (Delphy, 1970), defined the so-called rural development. This 'rural development' in the Global South was accompanied by the reproduction of the 'domestication' of women's work, women being considered as helpers to men (Perrot, 1998), and the exclusion of women in decision-making. As a result, domestic tasks that are not shared within the household to accumulate goods are disregarded (Hillenkamp, 2013) because they are non-market activities, since only the market creates value according to the capitalistic vision.

The kitchen: a place of power and oppression of women

In most societies, when performed day after day and passed on through the generations, such caretaking gestures become second nature for women (Tronto, 2009). The ambiguity of caretaking is that such tasks result from the socially constructed gender roles in which caretaking is mainly assumed by women: caretaking is prescribed, normative and imposed (Brugère, 2010). This situation also reflects what women wish to provide for their family: an act of giving, forged by upbringing and socialization. Women are expected to cook with attention, love and pleasure (Guétat-Bernard and Sébastia, 2022). This socialization puts a priority on relationships (Pulcini, 2012) and for this reason, it is precious for families and for the whole society, as it ties women to finding ways to ensure household FSN. It is also discriminatory to women, whose time is spent on tasks for which they receive no economic recognition and little social visibility, especially since women often bear the mental burden of organizing domestic tasks.

Among the spaces of caretaking, the kitchen is the heart of food issues: it is a political space that reveals the way women are assigned to the home (Tillion, 1966), as well as where games of power within the home, and more precisely the kitchen, play out (Guétat-Bernard and Saussey, 2014; Mathieu, 1991). The kitchen is an essential space where food enters for meal preparation and comes out to feed the household. Observed cooking practices thus reflect an environment that is both ecological (itself affected by the consequences of productive choices) and cultural (what is permitted or prohibited), as well as a political and religious ideology. These practices also translate the strategies of individuals in the context of the socioeconomic and political environment in which they evolve.

The kitchen: a place where women can express their skills, know-how, creativity and resistance

Reversing the stigmas of being in the kitchen, women take on their role by defending an ethic of both responsibility and rights (Larrère, 2012). The kitchen can also be considered as a place of resistance, as it is a marker of cultural identity and the expression of women's creativity. It is in the kitchen that women can invent recipes and apply the traditional knowledge, know-how and skills that give them social recognition (Counihan and Siniscalchi, 2014). Food is then reconsidered in relationship to the self and the world: in the kitchen, women demonstrate inventiveness that may be seen as a form of self-expression and as a way of communicating to their guests (Begin, 2017). Cooking is something that connects people and creates social ties, a practice that can ensure recognition of one's individuality.

⏩ Analytical framework of gender relations in household FSN

The studies carried out in Senegal and in Nicaragua are based on a holistic, systemic and multidisciplinary approach of FSN. With their own specific methodology summarized below in Figures 6.1 and 6.2 (Clavel et al., 2018; Fréguin-Gresh et al., 2019), both situate the spaces and flows that structure family food systems at the heart of their analytical framework.

Analysing the food supply strategies of multi-situated families in Nicaragua

The case study in Nicaragua is based on the analysis of food supply strategies of multi-localized farm households, in a context of increasing migration. The framework (Figure 6.1) shows the connections among three spheres (Gastellu, 1980): 1) domestic spaces, formed around the kitchen (sphere of consumption), which include individuals who eat together, considering that some members eat outside home or that others, who are not necessarily family members, may eat meals with the family; 2) productive spaces (sphere of production), which refer to the economic activities of family members and the flows of food and money they generate and which supply the kitchen. These productive spaces extend beyond the boundaries of the farm and those defined by the economic activities of a household in the strict sense of the term; they cover the activities of migrants and their related remittances; and 3) circulation spaces (sphere of circulation), in which different streams of food and resources occur: remittances, food aid, bartering, gifts, etc.

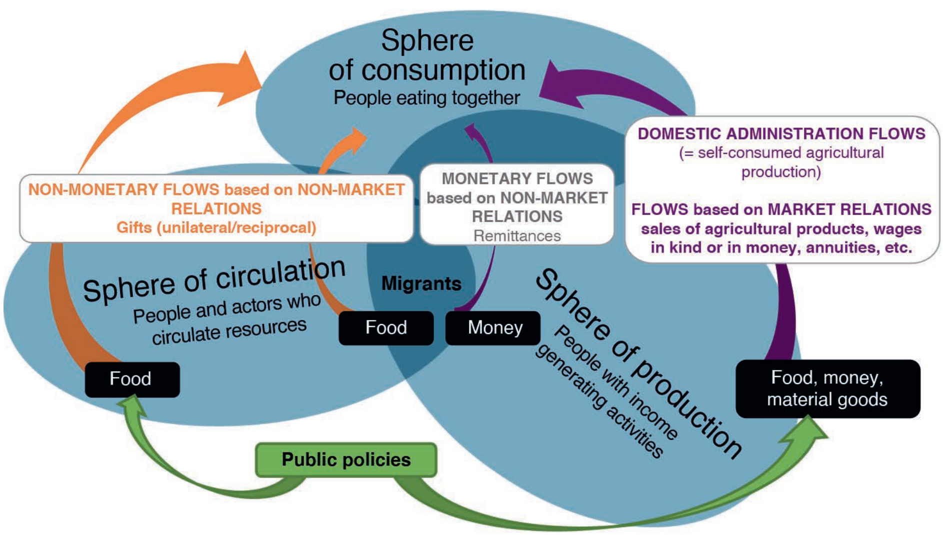

Figure 6.1. Analytical framework of the household food supply in Nicaragua (conception: Fréguin-Gresh, Cortès, Bannoviez-Urrutia and Guétat-Bernard).

Based on a household survey and semi-structured interviews, the methodology consisted in positioning each individual, including women, within those interconnected spaces. The nature, intensity and direction of flows depended on the relationships inside and outside the household, and on those formed with the institutional environment in which the family evolves. Those relationships are considered in terms of domestic administration, monetary or non-monetary relations, and market or non-market relations, in line with the work of Polanyi (Polanyi, 1983).

An approach centred on women's work in domestic and agricultural spaces in Senegal

The case study in Senegal aimed to understand the impacts of rice intensification on agricultural biodiversity and food quality. In line with the expectations of a local NGO,[9] the challenge was to design a transdisciplinary approach using agronomy, social anthropology and nutrition sciences. The aim of the survey was to document women's practices and knowledge, and to clarify the impacts of agricultural changes on the nutritional quality of food. The analytical framework considers streams of money, food and labour in three interconnected spaces: 1) the kitchen; 2) the farm; and 3) the socioecological space (Figure 6.2).

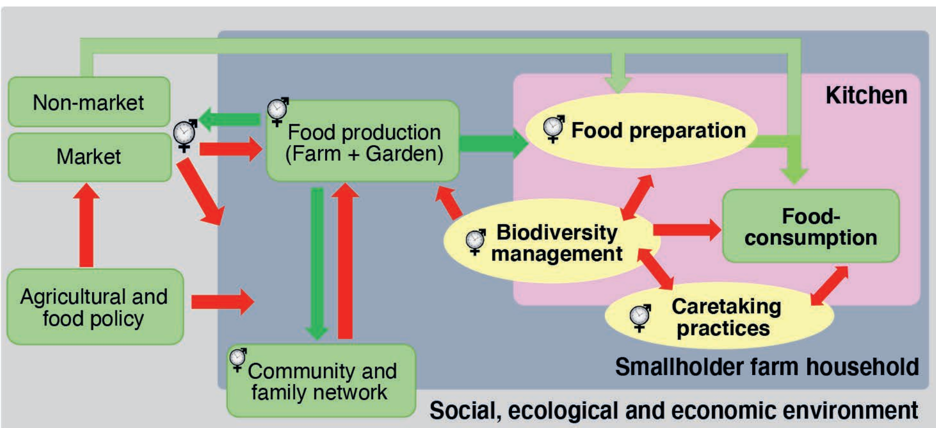

Figure 6.2. Gendered analytical framework of the household food supply used for family farming in Senegal.

The green, blue and pink boxes represent the three spaces of the food system and arrows represent the flows (green for food and red for influence flow including monetary). The orange boxes represent the main components of the food system and the yellow ovals represent the components in which women are more closely involved. The clock symbol highlights components that require time.

9. The study drew on the expertise and facilitation of the Senegalese NGO ENDA, which develops agroecological gardening activities with women as well as links with maternal and child health centres.

⏩ Women's work and gender inequality in agriculture and food systems in Nicaragua and Senegal

Agricultural and environmental contexts

Contextualization of the case studies reveals specific gender relations forged by a highly constrained environment and a sexual division of labour that disadvantages women. Both study regions are subject to climate and natural resource constraints that have shaped their agricultural and sociocultural dynamics.

The study region in Nicaragua is situated in the north-eastern part of the dry corridor of Central America. It is exposed to high climate variability and regularly affected by climate events. The topography influences agriculture: the alluvial plain is cultivated year round (maize, beans), while the bed of the Rio Negro, which marks the border with Honduras, can only be cultivated (sesame, watermelon) in the dry season when the waters recede. The interfluves are used as pasture for cattle ranching. In the mountains located in the north-east, the climate is more favourable and enables up to three cropping seasons per year (maize, sorghum, beans), but the rugged topography limits yields. Consequently, family farming has developed there in restrictive conditions that limit food availability, especially since gathering, fishing and hunting activities are hampered by deforestation.

The study region in Senegal is the middle valley of the Senegal River, at the heart of the Sahel. The vast floodplain, consisting of the riverbed, known as the *waalo*, is largely fed by the seasonal flooding of the river. In the *waalo*, families practice flood recession agriculture, fishing and livestock farming. Agriculture was disrupted by the dams built in the 1980s, a pressure that was subsequently accentuated from 2010 onwards by the National Programme for Rice Self-sufficiency (PNAR), which transformed the alluvial plain into a network of rice plots. Flood recession sorghum, as well as cowpeas and maize using varieties adapted to the flood recession crop system, are becoming rare, despite the cultural attachment of people to these crops. The people generally know the nutritional contribution of sorghum. But, with the advent of the PNAR, only rice cultivation gives people access to crop and marketing facilities. Thus, men and women are obliged to work in rice plots, and rice has become the main cereal in diets. Restricting the river's flow and level has also resulted in the disappearance of fish and has limited transhumant livestock farming.

Women's contributions to productive spaces lacks visibility

In Nicaragua, women usually do not work in the fields (except during harvesting or occasional tasks) or in the pastures, since cattle ranching is a symbol of social status for men. Women are often barred from inheritance (Fernández-Poncela, 1999), and so dedicate themselves to domestic production: tasks of daily life and caretaking, backyard livestock farming, and on farm processing of agricultural products, which are sold in the neighbourhood or on local markets. Selling raw materials (sesame, cereals, beans and milk) is restricted to men, who also decide how farm labour is organized. Non-farm diversification is essential to meet the needs of the family, since farm production is insufficient. Men are therefore also agricultural wage earners and women may run a shop from their window. Like landless farmers, they also collect calabash gourds (*jicaro*) to extract their seeds to make beverages (Banoviez-Urrutia, 2016). Finally, men and women may migrate. Migration has steadily increased over time (Carte et al., 2018). Men and women leave to work temporarily or more permanently in the neighbouring countries or internationally, depending on their resources (Trousselle, 2019).

In Senegal, women work in the fields and pastures, as helpers to men. They may also work with other women to cultivate common gardens that are allocated to them (by men) in order to diversify production. All products grown supply kitchens and markets. As in Nicaragua, the women process and sell farm products, such as the traditional condiment *nététou* made from fermented and crushed seeds of the African locust bean tree (*Parkia biglobosa*). Men cultivate rice (with women taking part in weeding and harvesting), practice pastoralism and are responsible for selling raw products (rice, onions and tomato). The organization of women's work is subject to the availability of men who can migrate temporarily or permanently, a long-standing practice in the region. Women do not migrate, except when they marry due to the tradition of patrilocal residence.

Cooking, skills and know-how of women in securing the family diet

In Nicaragua, diet is limited to staple foods, grown on the family farm: maize (and sorghum) used to make tortillas and other dishes (*nacatamal*, *güirila*, *cebada*) or beverages (*pinol, pinolillo*, *cebada*); rice, which is produced elsewhere or imported, is mixed with red kidney beans, which are often the only source of protein, used to make *gallo pinto*, the national dish. Other foods are consumed occasionally: dairy products, other animal products (eggs, meat, fish), and cultivated fruits and vegetables, which are either farmed or purchased. The families acknowledge that diet has improved over time. However, they have noted an upward trend in food prices, which is a risk factor for food insecurity. Food vulnerability and nutritional deficiencies are more pronounced in women, even though they play a decisive role in coping strategies to tackle household FSN (Marselles, 2011). Women have also continued to invent recipes and strategies to compensate for food shortages. They thus organize food bartering with their extended families and neighbours, even over long distances. Food bartering concerns festive dishes, but also staple foods. It is facilitated by multi-localization of family members. Food bartering is important in improving diets and helping to maintain social ties.

In Senegal, diet is based on traditional dishes made with sorghum, the emblematic culinary heritage of the region, combined with vegetables and seeds produced and/or gathered in the *waalo*. The women grow squash (*dédé doudé*) for their seeds (*beref/podé*), yellow-fleshed pumpkins (*diayedjé*), cowpeas (*niebe*), browntop millet, a wild grass with seeds (*pagguri)*, and black rice *(sarna* or *maro balléo*). Families eat fish, either fresh or dried and wild fruits: water lily fruits (*tabbé*), for their seeds (*ndayri*) and bulbs (*dayeedji*), desert date fruits (*Balatines aegyptiaca*), which have high nutritional value and multiple other uses. Women usually process raw products to prepare those dishes. Traditional food from the *waalo* represents nutritional diversity and is a marker of identity. Families have a cultural, dietary and aesthetic attachment to flood recession sorghum. Their diet has nevertheless deteriorated with the reduction in fishing, livestock farming and vegetable production. The replacement of sorghum by rice and wheat (white bread) has contributed to that deterioration by the loss of fibre and important nutrients. It is also suspected to contribute to the increase in chronic diseases (Crenn et al., 2015). In short, women's knowledge ensures a diverse diet. Women hold most of the knowledge related to seed conservation and recipes, which are often kept for special occasions and seasonal rites. Because sorghum is becoming scarce, its price is now double the price of rice, and certain families sell it when they suffer food shortages. Some recipes are linked to the identity of the *waalo*, such as dishes made with ground squash or pumpkin seeds or broken sorghum (*niri*), along with milk or dried fish. Women expressed some pride in maintaining this food heritage through transmission to their daughters. Individual and family memories value the *waalo* as a nourishing space and time, one of family gatherings during sowing and harvesting. Nowadays, farming the *waalo* is becoming increasingly difficult, as the plots not used for rice are farther and farther away from homes. Wild fruit gathering is neglected due to a lack of resources and especially time (domestic tasks, irrigation of rice paddies and market gardens).

Migration and agricultural change as spaces of resistance and creativity for women

Migration has a mixed impact on family diets in Nicaragua. The expansion of the circulation spaces continuously reconfigures the social organization of families and the socio-gendered distribution of labour within households. When men migrate, their absence means that economic activities are delegated to other men, with the migrant continuing to make decisions from abroad. In some cases, the women take over decision-making and take on activities that are usually restricted to men, deciding how to allocate the money sent by men for everyday spending and deploy off-farm activities. These changes are reinforced when women migrate. Since remittances are higher than local wages, female migrants become the breadwinners for their households, acquiring new economic and symbolic power. Women's remittances are crucial for FSN, but also for children's education and personal spending, sometimes with consumerist overspending to compensate for missing loved ones. Female migration is socially accepted and justified, even at the cost of the suffering caused by absence and the disruption of family organization. Women are only able to migrate thanks to intra- and intergenerational solidarity with other women. Households with at least one migrant member can improve their FSN. This improvement is both quantitative and qualitative, in particular with the introduction of new recipes or exotic foods, although these may not always be well accepted locally and not necessarily contribute to a balanced diet. At the same time, remittances introduce changes in consumption habits, such as purchases of ultra-processed foods sold locally at low cost. Such products contribute to the dual burden of malnutrition. But this transition cannot be blamed solely on migration, since it results from factors including a long-standing dependence on food imports (Fréguin-Gresh and Cortès, 2021).

In Senegal, the transformation of the *waalo* is cited as the main reason for abandoning sorghum production. Women combine labour in rice paddies and in increasingly reduced diversification spaces (as narrow banks of the river) to compensate for the decline of sorghum in the diet. The main women's innovations consist in vegetable cultivation by developing irrigated gardens. Modes of sociability are also evolving with the difficulty of settling near flood recession fields, when services are all concentrated in villages, and with the unavailability of child and adolescent workers, who are now in school. Despite the increase in rice production, the lean season (April to July) remains critical: this is a constant concern for women. They describe a change of status in terms of working the land, shifting from a situation in which they are recognized for their skills and knowledge, to one of helpers in rice cropping under the supervision of men. Wives, even when they are head of the farm (widows), suffer from a denial of recognition in the collective structure of water management and thus are not involved in decision-making about water management in rice farming. The community gardens are new initiatives by women's groups, which receive no technical support from the state but do receive some financial and technical support from NGOs. These irrigated gardens have an essential role in food diversity. Women sell some of these new varieties of fruits and vegetables on local markets, but organic vegetables are mainly self-consumed, as they do not fetch higher prices on the markets. Sometimes women grow conventional products for the market and keep the 'non-poisonous' products (as they describe them) for their family. The local markets are nevertheless a new source of own money, albeit a very marginal one. These gardens provide access to vegetables that were previously overlooked, which is a source of pride for women. However, land provided by men is not always of good quality and may be too far away. These gardens for women are also places of solidarity between neighbours or within the family. Thus, if a woman is unable to work, another will take on her work, and the favour will be returned. Likewise, the division of vegetable production between wives in charge of meals is done fairly. These rules governing daily cooperation between women and shared planning, to provide appetizing dishes every day, can be jeopardized by tension between co-wives. In this case, the quantity, quality and aesthetics of food become a factor of competition.

⏩ Conclusion

The two case studies took a systemic approach to FSN that places the kitchen at the core of food strategies and connects domestic and productive spaces on different scales (individual, household, family, location, and region, as well as migration spaces in the case of Nicaragua). Although the projects were specific, despite the different contexts, they both considered FSN as a complex issue, whose multiple dimensions (social relations, agro-biodiversity, identity and sensory dimensions) are embedded and interconnected.

The centrality of the kitchen in the analysis, as a strong methodological option, made it possible to at least partially deconstruct the conventional units used to study FSN that are problematic. Indeed, the household covers very different anthropological realities depending on the history and the culture of the people studied, and ignores inequalities between individuals. The results highlight certain unconsidered and overlooked aspects of women's roles in FSN, such as the contribution to incomes of off-farm economic activities that can be located in different places, the importance of food circulations based on social relationships between extended families and communities, the disregard of feminine activities, and the constraints women face to exercise their roles. Regardless of who is responsible for family access to meals, food circulation and preparation are organized by women. The kitchen is a fundamental space for socialization and knowledge exchange. The tasks conducted there are various, complex and time-consuming, yet the key role played by women is still not recognized as essential, sometimes even in the eyes of women themselves.

Consistent with the way knowledge and practices of dominated subjects are belittled, ignorance and discrediting of women's food-related knowledge and practices are similar in nature to the (post-) colonial relations pursued by contemporary development policies. Asymmetries of power continue to deny women's rights (especially to land) and fail to acknowledge women's expertise in food, agriculture and the environment. Although certain policies make women's empowerment central to guaranteeing FSN (as is the case of the Zero Hunger programme in Nicaragua), such policies are nevertheless still limited to domestic production, without any real paradigm shift. However, our research shows disruptive effects (in roles, know-how, etc.) on the already fragile balances involved in efforts to ensure FNS by women; these disruptions tend to increase the food and social vulnerability of women and their families.

The long history of patriarchy in many societies explains the hierarchy of activities between those that are socioculturally dedicated to women and those dedicated to men. But, it is the continuous discrediting of women's food-related knowledge in the name of FSN that women come up against. Although the projects did not focus on social movements, they do highlight the existing spaces of low-noise resistance that need to be acknowledged and understood when implementing development programmes. Women do play a central role in food systems but have poor access to resources and reduced power to assume these roles. Thus, interdisciplinary and contextualized research analysing the issues at stake in domestic spaces produce results that are crucial in guiding public policies. It is essential to pay attention to women's voices, and to understand how they approach food issues, in order to implement the actions they deem relevant.

⏩ Acknowledgements

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Chapter 7

Agroecological innovations, food and nutrition security and food safety for small farmers: Africa-Europe perspectives

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In both the Global North and Global South, food, nutritional and even safety insecurity mainly impact the most vulnerable populations. Among those, the urban populations of working-class neighbourhoods in large and medium-sized cities are the most affected, as well as rural populations making their livings from small family farming, especially in Africa. However, in many situations, innovations (technological or organizational) are emerging and profound changes are under way, whether or not accompanied by incentivizing policies. We can thus observe a transformation in agricultural and food production systems, which are gradually or radically integrating more agroecological farming methods: a combination of crops and livestock, introduction of off-season market gardening, fruit arboriculture, and more.

These transformations are sometimes based on eliminating pesticide use, such as in organic farming. The changes, often guided by market considerations as well as societal expectations about the environment and health, are likely to have positive impacts on not only the environment but also producer and consumer health through healthier, safer and more diversified food (Dury et al., 2019; Bezner Kerr et al., 2021). In cities or on their outskirts, especially in Europe, the growing development of multifunctional urban agriculture can also have positive effects on the environment and the food and nutrition security of vulnerable populations. This includes community gardening in working-class neighbourhoods that creates multifunctional spaces, which then strengthens links with nature and social ties, well-being and educational aims (Lal, 2020).

These different elements led us to ask the following question: do these innovations contribute, directly or indirectly, to improving the availability and accessibility of quality food products (with high nutritional, sanitary and organoleptic value) for farmers and practitioners of these forms of urban agriculture, thus helping to strengthen their food security? To study the existing links between farming methods and dietary diversity, we analysed three contrasting case studies in Africa and Europe and the obstacles encountered. We will first present the main methods and results of each of the three case studies before discussing the similarities and differences observed.

⏩ Presentation of case studies and main results

Diversity of farms and food diversity in the Sudano-Sahelian region

The study was conducted in the province of Tuy, in the Hauts-Bassins region in western Burkina Faso. The climate is tropical with two strongly contrasted seasons: a dry season from November to April and a rainy season from May to October. The main economic activity is agriculture, although gold ore mining, both industrial and traditional, is gaining in importance. Agriculture in this area is mainly family-run and rain-fed, based mostly on cotton-cereal rotations (maize, sorghum, millet). The harvest period is from October to January, which makes it possible to fill the granaries, harvest the shea (*Vitellaria paradoxa*) and locust bean (*Parkia biglobosa*) fruits from the agroforestry areas that will be processed and stored, and generate income that will ensure most of the household food supply during the year. Most farms also keep animals, but mainly for animal-powered transport or sale (including small ruminants and poultry) rather than for self-consumption. Some farms have orchards, especially mangoes, which are an important source of food during the lean season, not only for farms' own households but also for all families in the community. Some farms have access to lowlands where they can practice market gardening during the dry season from January to May, which allows farmers to have fresh fruit and vegetables for their self-consumption and to sell in local markets to other inhabitants of the region. The annual diet is thus based on basic foods that can be stored and bought locally throughout the year: cereals that women grind to make *tô* balls (maize, sorghum, millet); sauces and condiments; snacks (vegetables, fruits) that may be fresh or processed to be preserved; sumbala (fermented locust bean seeds), chilli peppers, dried fish, etc. Despite this careful management, in a constrained environment, the dietary diversity scores measured among women remain low (Lourme-Ruiz et al., 2016).

A longitudinal study was conducted on 300 farms across 12 villages in Tuy over a one-year period, from October 2017 to September 2018. The aim was to record farming practices and dietary diversity among women (24-hour diet recall) over a complete farming season, from the harvests of one year to the harvests of the following year.

We used the data collected to build a typology of farms, based on a principal component analysis (PCA), and an ascending hierarchical classification (AHC) on the basis of the following variables: cultivated area (total in ha, for cotton and legumes), equivalent-adult workers, number of draft oxen, income, Simpson's Diversity Index, (left-hand column of Figure 7.1, from bottom to top). It includes four types:

1. Medium-sized cotton-oriented but diversified family farms (type 1, n=95);
2. Small farms with land constraints oriented towards livestock (type 2, n=28);
3. Farms producing legumes (20% of crop rotation) with land constraints (type 3, n=68); and
4. Large family cotton farms (type 4, n=100).

Links were then established between these four types of farms and 15 specifically constructed indicators of the ecological practices (e.g., percentage of the agricultural area on which manure is spread; use of crop residues; doses of artificial fertilizers; density of trees in fields). These indicators were grouped into four types of practices (A, B, C, D), according to the PCA and AHC (middle column of Figure 7.1, top to bottom):

1. The use of artificial inputs (A, 169);
2. Agroecological practices involving an optimization of the use of manure and a high density of trees in the fields (B, 39);
3. Agroecological practices involving an optimization of manure and crop residues (C, 29);
4. Agroecological practices involving cereal-legume rotation and a minimization of tillage (D, 54).

These cross-linked typologies (farm type, groups of practices) were linked to the dietary diversity score of the women surveyed. The score was simplified according to the number of months during which the score is higher than the annual average (right-hand column Figure 7.1, from top to bottom): more than six months of the year (39); fewer than six months of the year (204); and no months of the year (48).

Figure 7.1 shows the links between these three pillars and illustrates the complexity that exists between agricultural systems, agroecological practices, and dietary diversity among women. While the two types of cotton-oriented farms (1 and 4) are unsurprisingly the two largest users of fertilizer (links with input supply chains through monitoring of the cotton sector), all types adopt agroecological practices. More specifically, the two cotton-oriented types mainly adopt practices related to the management of crop residues (C), while the two other types of small family farming, constrained by land tenure (type 2 and 3) adopt the whole range of agroforestry practices (B, C and D). The right-hand part of Figure 7.1, which shows the links between agricultural practices and dietary diversity, shows that the best and worst levels of food diversity can be obtained by any type of agricultural practice. However, we can note that for 23% and 24% of farms that are classified in type B and C, the agricultural practices are at the highest level of dietary diversity, while only 12% and 15%, of types A and D, respectively, achieve this level of diversity.

These results, which are quite complex to interpret, illustrate a striking fact: dietary diversity does not just depend on farm production or harvests; it is also a question of households having market access and earning a sufficient income to purchase diversified food products. However, what this graph seems to indicate is that, in this region of the world, cotton-oriented farms, even if they adopt agroecological practices, and in particular cereal/legume crop rotations, do not present the greatest dietary diversity over the course of the year. Conversely, small farms that are constrained in terms of land use adopt a wide range of agroecological practices that make it possible to achieve high levels of dietary diversity.

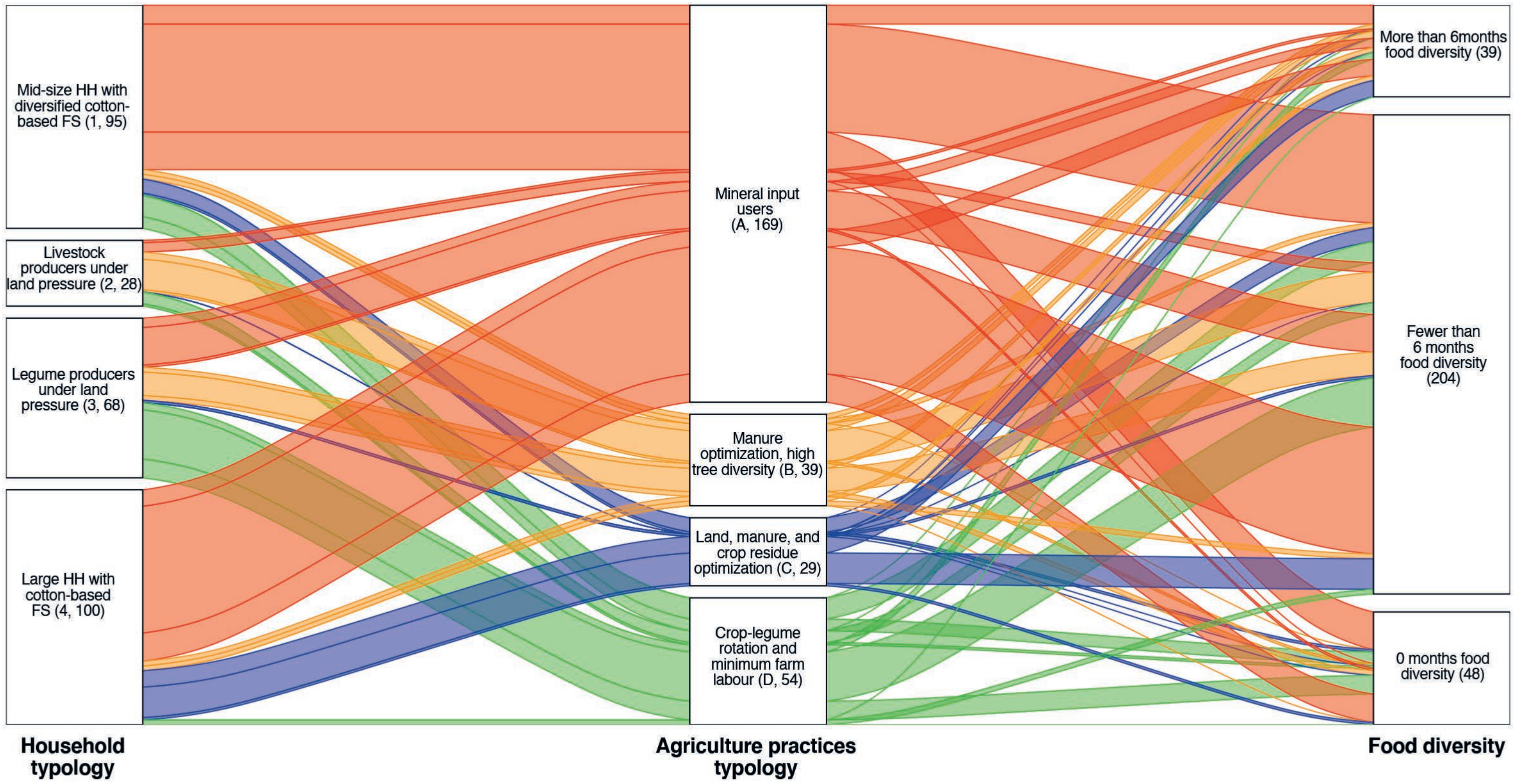

Figure 7.1. Links between the classes of household typologies, agricultural practices and dietary diversity for 300 farms in 12 villages in Tuy (Burkina Faso). The colours and line thickness indicate the size of the number of farms involved.

Beyond the preliminary results presented here, two complementary challenges remain: first, How to encourage all types of farms, and in particular those oriented towards cotton production, to adopt agroecological practices? And second, How can direct and ethical links be established between agricultural practices and dietary diversity, by making dietary diversity an explicit decision-making factor in the choice of agricultural practices, and by making it a family issue in the same way as agricultural yields? This concerns issues of decision-making between men and women, and thus of gender and power, regardless of the capital constraints of the farm.

New forms of organic farming in Africa and their contribution to the food security of farmers and the whole population

Organic farming is experiencing renewed development in Africa (Lernoud et al., 2019), but it covers very different realities. After conducting several workshops and surveys between 2015 and 2018 in Burkina Faso, Cameroon, Benin and Senegal with actors involved in organic production objectives, we created a typology of organic farming situations according to the innovations implemented by farmers. We then characterized the way that greening production methods through organic farming can directly or indirectly influence food security through self-consumption or higher incomes.

Typological characterization of organic farming and producers' innovation situations

Three main types of organic farming have been identified (De La Paix, 2020) to describe innovation situations that lead to greening of production methods and contribute to an 'agri-organic' transition:

1. Certified organic farming, aimed at international markets. It is implemented by multiple stakeholders (e.g., industrial entrepreneurs, civil servants) or companies already engaged in international markets (bananas, pineapples, cereals, and legumes, especially soyabeans to supply organic livestock). The production method mainly uses hired labour. This form of agriculture promotes its organic nature and complies with the specifications established by organic farming certification bodies at the production and processing levels. The markets targeted are clearly international (Europe, North America).
2. Organic farming described as 'natural', targeting local markets. We note here the term 'natural', which arose during workshops in Cameroon. It refers to agricultural and food systems that have existed for generations and where chemical inputs are not used, either by choice or because of financial or biophysical constraints. Often based on highly diversified systems (crop combinations, rotations, agroforestry, etc.), the products from these systems are most often very diversified: cassava, plantain, yam, fruits and vegetables (eggplant, tomato, etc.) and leafy vegetables (amaranth, vernonia, etc.), fruits and non-wood forest products. The term 'organic farming' is often not claimed. The targeted markets are local and sometimes regional (e.g., the Economic and Monetary Community of Central Africa – CEMAC). No third-party certification is applied; however, participatory guarantee system (PGS)

experiments are tested. These systems are built on trust between farmers, consumers and collectors. They are based on information systems related to the method of production, the geographical origin of the product and the social community. This form of agricultural production is predominantly family-run, sometimes with support from non-governmental organizations (NGOs).

3. Hybrid entrepreneurial organic farming, targeting the national market. This form of organic farming is the most heterogeneous. This type of agriculture often includes processing of products in various forms: juice, dried products such as macabo chips (*Xanthosoma sagittifolium*), flour, frozen foods (green beans), etc. The agricultural practices are slightly more intensive with the use of manufactured organic fertilizer or local biopesticides, while seeking to preserve a ‘natural’ character for the product. The ‘organic’ or ‘natural’ dimension of the product is highlighted, for example on packaging. In this type of farming, we also include agricultural systems inspired by specifications imposed by importing countries, such as healthy and sustainable agriculture in Senegal. These products are primarily aimed at the urban middle-class market. The actors associated with production or processing are entrepreneurs, sometimes organized in community groups (known as GICs) or small local cooperatives with or without the help of NGOs.

What these three types of organic farming have in common is that they do not use pesticides or chemical fertilizers. The elements of differentiation relate to the methods of production (family-run, employees), certification, and sectoral integration (industrial, artisanal, short networks) and the downstream recipient markets.

The attributes of food security linked to production system diversity

Using surveys carried out in the four countries studied, we attempted to characterize how the transition toward organic can directly or indirectly influence all aspects of food security.

Availability and access relating to the increase and diversification of production

The improvement in availability may be linked to an increase in the production of some agricultural goods, due to an increase in yields, but it can also be qualitative, through increased and easier access to more diversified products.

In areas that have undergone long-term intensive farming, which has reduced the fertility potential of agroecosystems, the changes brought about by organic farming are likely to restore the biological fertility of the soil. As a result, yields may increase, which is the case for coffee growing in western Cameroon.

In agroforestry areas that are mainly focused on cocoa and coffee production, the yields of these export crops are partly dependent on pesticide use. Eliminating pesticides as part of the transition to organic farming can be accompanied by an extensification of the plantation. The women who help harvest cocoa and coffee can then use the time thus freed up to produce food such as tubers, maize and other market garden crops (Temple and Fadani, 1997). The increase in the number of species and varieties grown can lead to a potential dietary diversification. The effects can therefore be negative for the main crop (accessibility), but positive for food production (availability, nutrition).

Accessibility by increasing income

Certified organic farming can increase producers' income thanks to the higher sales prices obtained on some products exported to Europe such as soyabean (Burkina Faso) and fruits and vegetables (Cameroon). It also creates salaried employment that improves food security in areas where land access is poor.

In situations where the number of intermediaries is reduced, organic farming helps producers earn higher prices; it potentially improves the food accessibility indicator for producers and consumers alike. It also allows food autonomy to be preserved through self-production, which remains structurally significant in sub-Saharan Africa.

In contrast, in areas of specialized monoculture (e.g., cotton, banana, rubber tree), chemical pesticide use is very high. Transitioning to organic farming imposes technical and economic changes that can reduce main crop yields, farmers' incomes, and the use of hired labour. The consequences for the 'accessibility' attribute of food security via this 'local income effect' can therefore be negative.

Food uses in relation to nutritional and health security

Numerous studies show that organic farming increases the nutritional quality of products (Hunter et al., 2011; Baranski et al., 2014). This increase is particularly marked for fresh fruit and vegetables. However, little research is available on the subject in the African context.

Because organic farming is free of chemical pesticides, it also reduces the risks of diseases linked to the handling of pesticides by producers or residues on produce reserved for self-consumption, thus improving the overall health of producers. However, public health indicators are very rarely provided in poor areas of developing countries and very few explicitly relate to the link with pesticides. However, excessive pesticide use is common, especially in peri-urban market gardening areas where soil and irrigation water are very often heavily contaminated by pesticides and toxic heavy metals.

The regularity of supplies, in quantity and quality

Certified or hybrid organic farming is often the driving force of a small industry of processed products (e.g., fruit juice, dried products). These new products, which have a longer shelf life than fresh products, give people access to new products outside the typical seasons, thereby contributing to food security during the off season or in lean periods.

Natural organic farming, which relies on crop combinations, can strengthen the resilience of cropping systems to climatic variations and pressures on plant health (Branca et al., 2013). However, the variability in the quality of products resulting from diversified farming rarely meet the expectations of the agrifood industry that consolidates products through large-scale processing, or those of large-scale distribution, concerned with marketing very standardized products. Strengthening a more decentralized artisanal industry, capable of making better use of this diversity, would contribute to develop this kind of agriculture.

Obstacles to the development of different types of organic farming

In certified organic farming, the main constraints are costs generated by third-party certification, the lack of technical assistance for farmers, and access to specific specific organic inputs. Finally, the smallest organizations can find it difficult to earn the loyalty of end buyers in destination markets due to strong competition in quality niche markets.

In 'natural' organic farming, the main constraints are inherent to the intensity of farm labour resulting from stopping the use of some pesticides. This mainly applies to herbicides such as glyphosate, used to kill weeds in the soil before growing most crops, or diuron and metolachlor, applied during the pre-emergence period for cotton crops. In addition, lower yields increase producers' sensitivity to post-harvest losses. Methods to protect against crop pests and diseases should be more integrated and complementary (genetics, cropping systems, plant fertility, mechanization, etc.).

The increase in the difficulty, intensity and amount of work imposed by organic farming requires either better remuneration for farmers or the activation of innovative processes by modifying cropping systems or introducing small mechanization interventions (weeding, irrigation, transport, and product processing).

With regard to hybrid organic farming, the main constraints relate to the structuring and consolidation of emerging niche markets. Another consideration is the difficulty of bringing about the emergence of certification systems, which secure the quality of processed products without incurring excessive additional costs.

However, some forms of organic farming structure the local collective actions (known as SPGs), or sectoral actions with new producer organizations. These changes can positively contribute to the food security of relevant populations, both directly and indirectly. Identification of all these collective actions and enhanced support of them through public policies and adapted research can help ensure effective transitions to organic farming systems.

The development of urban gardens in working-class neighbourhoods in Paris and Seville and food security

Allotment gardens were promoted in nineteenth-century Europe to encourage poor, urban working-class populations to produce their own food (Cabedoce & Pierson, 1996). Until quite recently, such gardens were virtually non-existent in predominantly rural countries and regions in Europe (such as Greece and Andalusia). Since the beginning of the twenty-first century, we have witnessed a triple evolution in western Europe: 1) the diversification of community gardening (shared gardens, allotment gardens for families in public housing estates) as a way to renew social ties and due to the interest of urban populations in ecological issues; 2) the emergence of urban community gardens in the countries most strongly marked by the 2008 crisis (Greece, Spain, Italy, Portugal); and 3) in all cases, the rise in agroecological practices in these gardens, often governed by charters (in France, *Main verte* or *Jardinons au Naturel*) or municipal or national regulations. The problems of food insecurity in working-class neighbourhoods are also worrying: in France, 14% of households in these neighbourhoods were food insecure in 2012 versus 6.59% of the general population, and these figures rose further with the health crisis of 2020.

To analyse the potential food functions of these community gardens, a comparative study was carried out in 2016 on four garden sites in Paris (and the inner suburbs) and four sites in Seville in Andalusia. The sites vary by the date of creation of the garden (from 1991 to 2014) and their origin (created by family associations in Seville and social associations or social housing landlords in Paris). The survey concerned 14 gardeners in Paris and 17 in Seville on a voluntary basis.

First, semi-structured interviews were conducted to understand the gardeners' social status, level of food insecurity (by applying the criteria adapted by Bocquier et al., 2015), food purchasing habits, history of their access to the garden, along with their expectations of the garden and the crops selected. Second, the gardeners recorded the dates and amounts of produce collected (mid-May to the end of October in Paris, April to November in Seville) in a harvest log that had been previously designed and tested (Pourias et al., 2016). Third, the uses of this production were monitored (fresh consumption, conservation, or given away because sales were not authorized). Researchers conducted bimonthly visits throughout these periods to gather complementary information and record the gardening practices.

The results (Pourias et al., 2020) show varying socioeconomic statuses and levels of food insecurity between the two cities: in Paris, none of the 14 gardeners surveyed (five retirees, one unemployed person, eight employed people) suffered from food insecurity, despite often having low incomes. Although we acknowledge a possible methodological bias in our study (since volunteer gardeners may not necessarily be the most concerned by food insecurity), we noted a very limited presence of the most vulnerable people in these gardens, which is confirmed by discussions with the social housing landowners who know these individuals.[10] In Seville, four of 17 gardeners (10 retirees, four unemployed people, three employed people) did not want to answer this question, four said they 'sometimes did not have enough to eat, or not what they wanted' and nine were food secure. In Paris, most fruit and vegetables were bought in local markets (which were considered as attractive places for prices but also for socialization) and, secondarily, in supermarkets or discount supermarkets; in Seville, produce was mainly purchased in supermarkets and discount supermarkets, with proximity and prices the main considerations. In Paris, gardeners always had a prior interest in fresh fruit and vegetables and cooking before participating in a community garden, and their participation enabled them to have better access to new or expensive products. Meanwhile, in Seville six of the 17 gardeners said that the garden had changed the way they buy and eat by giving them access to a greater variety of products. In fact, 15 kinds of vegetables and fruits (not including aromatic

10. The reasons given were varied: lack of time (in the case of single parent families, for example), sociocultural factors such as poor command of French, the lack of practice in working together, health problems, etc.

herbs) were produced on average in the Parisian gardens and 31 in Seville; in both cases, community gardens favoured food diversity.

The survey confirmed the high variability in quantitative production between gardeners and cities: from 2 kg to 117 kg per gardener in Paris and 61 kg to 531 kg in Seville, i.e., from 0.2 to 5.8 kg/week per gardener in Paris versus 5.3 to 34.3 kg/week in Seville (according to its nutritional guidelines, the WHO recommends 2.8 kg/person/week, WHO, 2013).[11] These differences can be linked to the milder climate and the longer growing season in Seville, larger plot sizes (from 25 m^2 to more than 150 m^2) than in Paris (maximum 20 m^2), as well as the time devoted by the gardeners and their agricultural experience and knowledge, which were more significant in Seville. The contribution of this self-production to household food is, whether in Seville or in Paris, mostly seasonal but clear (Figure 7.2) and recognized, with a more substantial food provision function in Seville.

In both cities, the gardeners systematically highlighted the quality of their production (taste, freshness, and trust, because it is 'homegrown without any chemicals'). Some talked about 'exceptional products' 'that one never throws away' (unlike supermarket vegetables). Conservation (canning, freezing, jams) only concerns the largest 'producers' in both cities but giving away food was very common, both to family members in difficult situations as well as in external solidarity with neighbours.

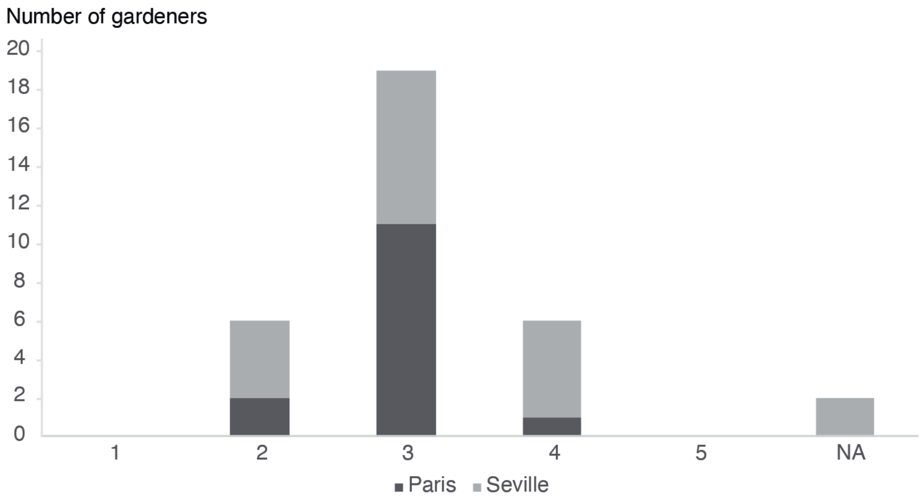

Figure 7.2. Extent of garden food production in Paris and Seville based on 33 gardeners' self-positioning on a gradient of 1 to 5 in 2016.

Each column represents the number of gardeners by classification (from Pourias et al, 2020). Gradients: 1) The food I produce in my garden is incidental, I almost never eat what I harvest; 2) I only occasionally consume the vegetables from my garden; 3) The food I produce in my garden covers 50% to 100% of my needs during the high season for at least one or a few products; 4) The garden allows me to cover all my vegetable needs during the high season (and occasionally out of season); 5) The garden covers all my vegetable needs year round (self-sufficiency).

11. https://www.who.int/news-room/fact-sheets/detail/healthy-diet

These findings are very similar to previous findings for all community gardens, whether or not they are located in working-class neighbourhoods (Pourias et al., 2016). With regard to working-class neighbourhoods, the relevance of these gardens for greater food security is consistent with the results observed in Greece (Partalidou and Anthoupolou, 2017) and Marseille (Martin et al., 2017), where even very low production is associated with significantly higher family consumption of fruit and vegetables. However, and in accordance with other researchers' findings, the very limited accessibility to these gardens among the most vulnerable populations should be noted. In addition, it was observed in Seville (but not in Paris) that the community garden could be a springboard for launching professional agricultural facility projects in agroecology and/or local sales;[12] these findings also agree with other observations (Segui et al., 2017).

These original infrastructures that make up urban gardens intended for food self-production can and should be integrated into development policies in working-class districts. The COVID-19 health crisis, which highlighted food and social problems in these districts, led the French Ministry of Agriculture to release 30 million euros at the beginning of 2021 to support community gardening in working-class districts. However, it is critical to note that self-production cannot be the only lever to guarantee food security for all and to restore food justice, which has been badly damaged in industrialized countries (Paddeu et al., 2018).

⏩ Conclusion

In this paper, we addressed several case studies, which relate to various agroecological and diversification transitions in both the Global North and the Global South, in urban as well as rural areas. The important point is that all these situations testify to positive effects, direct and indirect, on the attributes of food security (availability, accessibility, use, stability) for those who implement them. We offered an in-depth analysis of the nature of the links between productivity and food quality by specifying which components the changes in practices observed are likely to affect.

Availability, use and stability can thus be directly and positively influenced by the implementation of agroecological practices: agricultural diversification on farms in the Sahel and vegetable production in urban gardens directly provide easier access to a more diversified diet. Those who adopt these practices see increased availability, which in turn leads to better access and use (consumption in family meals). Stability also rises, with greater diversity in phenological cycles of the crops grown and even different forms of processing (drying, canning, etc.), improving the coverage of needs (in particular in micronutrients) over longer periods. Where they are used, 'organic' crop practices, whether certified or not, also offer better health outcomes, which can be undermined by the often massive and poorly controlled use of pesticides in peri-urban market gardening production (van Veenhuizen, 2006). They also allow access

12. Creation in 2016 near the Poligono district of a market gardening farm by three young people from the community garden and establishment of a small aquaponic production facility by a family in another garden, supported by the University of Seville.

to ‘organic’ products for urban populations who cannot afford certified products from branded networks in Europe.

The benefits of implementing agroecological innovations are also indirect, as these practices improve accessibility to a healthy and diversified diet in various ways. Thus, even if the direct increase in income (observed in the case of better market integration) does not systematically improve food security (controversies remain on this point, depending on the household’s prioritization of food), the different types of organic farming identified generate new opportunities in Africa for employment and small-scale entrepreneurship. These opportunities can be located upstream of agricultural sectors, via the design, manufacture and marketing of new products (local biopesticides, small-scale mechanization, etc.). They can also be located downstream of the sectors in agrifood processing or specific logistics set up beyond the production activity (small processing units, logistical and transport activities, social groups, information systems, opening of new markets, etc.).

Some forms of organic farming structure collective actions on territories (SPGs) or sectoral actions in some sectors (new producers’ organizations). These situations can be observed in both the Global South and the Global North in the case of allotments (new professional projects). While a thorough analysis of these new networks still needs to be performed, these networks certainly represent an important lever to improve the food security of relevant populations. Implementing networks of a different but complementary nature is also likely to generate positive synergies. The rise of ‘organic farming’ in Africa offers hope, but can only really benefit underprivileged populations in the long term if they manage to master the commercial levers, locally or for export. Thus, our studies show that the development of agroecological practices in fragile environments and in populations at risk can constitute an important lever to improve the food security of these populations. Additional research is, however, still needed to better understand the determining factors of food security and the nature of the complex links between production and food security in order to shed light on the necessary renewal of public agricultural and food policies.

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Section IV

Innovating processing for high-quality foods

Chapter 8

Reducing food loss and waste in meat and fruit supply chains: how food engineering can help

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Plant and animal products are seldom consumed immediately after harvesting or slaughtering, which means appropriate measures (processing, conditioning, storage) must be taken to ensure food safety. As the number of processing and distribution steps multiplies, the inevitable result is food loss and waste (FLW). *Food losses* occur along the food supply chain from harvest (or slaughter) up to, but not including, the retail level, while *food waste* occurs at the retail and consumer stages (FAO, 2019). While FLW occur across the entire supply chain, they reach their maximal level at the end of chain, i.e., households or catering. The European Union (EU) has set a target to halve its food waste by 2030. Extending product shelf lives through optimized, innovative processing and preservation technologies is a key way to reach this objective. It is therefore urgent for the policymakers and for all the players involved in the supply chains to quantify the impact of processing and preservation technologies on FLW reduction to assess the benefit/cost ratio of FLW reduction achieved using innovative technology and the trade-offs involved.

It is important to mention that the FLW discussed in this chapter focuses on the decrease in quantity and quality[13] of food at processing, distribution and consumption steps caused by a lack of processing and preservation technologies, and/or poor grasp of these technologies by food chain stakeholders (including consumers). FLW studied here do not include FLW due to farming and harvesting, and more generally post-harvest losses, i.e., those occurring before a product reaches processing facilities. Our main question is to quantify the impact of processing technologies on FLW mitigation. Other mitigation actions not directly related to optimization of

13. Decrease in quantity refers to food that exits the food supply chain, while decrease in quality refers to the decrease in food attributes that reduces its value in terms of intended use (FAO, 2019).

processing and storage, such as programmes to redistribute foods that are about to expire, are not in the scope of this study but could be found in other initiatives (see, for example, the European project Reamit, Interreg, 2021).

This chapter briefly presents the results on FLW reductions obtained within a meat supply chain and a fresh fruit supply chain. Common perspectives are then discussed to further reduce losses in these chains through well-optimized processing and preservation technologies using a generic food engineering approach.

⏩ Objectives and approach

Our objective was to quantify the share of FLW caused by a lack or poor management of preservation technologies in two types of food supply chains: meat, and fresh fruit and vegetables (F&V). The first step was to study the impact of processing and preservation technologies on product shelf-life extension and the concomitant FLW reduction obtained at the different stages of the post-slaughter and post-harvest chains. To do this, we first used food engineering approaches based on the development of mathematical models. Such approaches are crucial because efficient processing, preservation, and packaging prevent losses not only in the factory or during food distribution, but also in consumers' homes. The second step was to link the product shelf-life extension to a decrease in FLW at different stages of the food chain, and especially in households. Making such determinations required experimental data on FLW. Given that such data were scarce and fragmented, surveys were carried out to get more information on FLW at the different stages of the meat and F&V chains. Where possible, the impact of stakeholder and consumer behaviours, such as common practices, knowledge and beliefs about the technologies used to preserve their food, was also included for FLW prediction. Published data on FLW often confuse losses due to degradation reactions and wastage of edible food (due to unpredictable behaviour of consumers, who sometimes discard edible products). As a result, published FLW data did not clearly quantify the share of losses that food technologists could improve.

Two types of biological phenomena with an impact on retail products can explain the loss (or rejection) of foods by consumers: 1) the growth of spoilage microorganisms and 2) biochemical degradations. It is often important to consider both phenomena to predict and prevent food chain losses. In practice, many processes can improve food preservation and limit losses, and they can often be combined or adapted for greater efficiency. Research has been conducted on meat to develop processes that are adaptable and affordable, or which can be applied at different scales, both in France and South Africa. These processes are similar to the approach used to disinfect water using solar energy (McGuigan et al., 2012). Since food quality is multi-faceted, and durability is major issue for processes, multi-objective modelling was an interesting way to properly address the problem. Research on the F&V chain focused on strawberry, an emblematic fruit in France. As a highly perishable product with very short shelf life, strawberry is the most difficult case study for the overall F&V chain. In this case, work focused on quantifying shelf-life gain and concomitant FLW reduction achieved in the post-harvest chain by using well-designed modified atmosphere packaging, either in addition to, or instead of, the exclusive use of cold storage. Mathematical modelling was indispensable to explore the many different post-harvest scenarios and consumer practices.

Loss and waste along meat chains

Compared to plant protein production, producing meat protein requires more energy, land and water and generates more CO_2 emissions. The result is a greater environmental impact. Moreover, world population growth and rising living standards have increased the demand for meat protein, which is unlikely to be satisfied in the future. It is therefore critical to limit the losses at every stage of the chain. In particular, controlling the cold chain and using appropriate packaging is crucial to limit FLW. In Western countries, most meat is sold after slaughter and butchering. In the Global South, where the cold chain cannot be guaranteed to keep meat fresh, meat is often stabilized using traditional processes – e.g., salting, drying, and smoking – to be consumed later or to be transported to remote areas. FLW were compared in two different countries, France and South Africa.

Fresh meat chain in France

Because data on FLW are scarce, we conducted a survey to evaluate FLW in a French context to determine the step at which most losses occur within the fresh meat chain. Data were collected from five companies located in the Auvergne-Allier area (central France), including small companies engaged in regional trade and larger companies engaged in national or international trade. The results showed that losses were very low in factories during meat processing, while they became significant during food distribution (Comparet et al., 2016). While the losses appear small (2% to 4% of production), they must be put into perspective because they represent significant tonnages. Additionally, only big supermarkets were surveyed, but losses are known to be higher in smaller stores due to lower activity levels. Moreover, the impact of these small losses can be very high in terms of sustainability, especially for the beef industry; some authors estimate that a 3.5% loss of beef in a supermarket is equivalent to 29% of overall food losses when translated into a carbon footprint (Eriksson et al., 2014). Based on the difference of the total amount of loss already known, the most important conclusion of our survey was that fresh meat losses occur mostly in consumer homes. This can be partly explained by better food preservation control by industrial players and distributors. Professionals also minimized storage duration, which transferred FLW to the end of the chain (i.e., consumers). One technical solution for the microbial stabilization of meat using flexible processes is the heat treatment of the meat surface, which is contaminated during slaughter and successive cutting of muscles. Prior research has proven that flash heat treatments can be an effective way to decontaminate the surface of carcass and muscles, while further recontamination can be controlled by using natural chemicals (Kondjoyan and Portanguen, 2008; Lecompte et al., 2008). However, consumers often find even natural preservatives to be less acceptable. Thus, the formation of a dried crust over the meat surface, by further heating, was considered in our project to avoid surface recontamination and microorganism growth. But this barrier effect is only effective until the crust is rehydrated. We performed calculations to estimate the time during which the crust will remain a barrier against recontamination. Under usual temperatures and packaging conditions, the crust loses its barrier effect quite rapidly. Thus, the crusting technique would have to be combined with modified packaging to control the humidity and/or gas composition of the product environment.

Processed meat chain in South Africa

The consumption of livestock and game meat is widespread in South Africa. Traditional processed meats such as biltong (a small piece of meat, cured with salt, vinegar and spices, and then dried) and droëwors (literally, 'dry sausage') can be preserved without cold storage. The traditional sector of these intermediate moisture meat products in South Africa is becoming more and more industrialized to meet rising market demand. The objectives of our project were to 1) better understand the FLW due to meat processing, either in artisanal or industrial units, and 2) study the mass transfers that occur during processing and their effects on the quality criteria. The focus was the control of the process, based on a global mathematical simulator, considering the change in product quality during the three main processing stages (tumbling, drying and storage).

To achieve the first objective of better understanding the FLW during meat processing, a survey was conducted of the main biltong manufacturers and distributors in the Western Cape province of South Africa (Beyers, 2016). This study identified that manufacturing generates very few losses of a non-quantifiable level. In fact, during meat preparation, meat pieces that are not large enough for biltong and other trimmed scraps are used to make droëwors. In addition, the biltong distributors very rarely return products to their suppliers. When they did, most of the time it was because of mould development. Moreover, the distributors destroy marginal quantities when the products approach the end of their shelf life. Sometimes, when there are issues with the finished product, such as when it too dry, they will turn it into powder for use by the food industry or in pet food. The concept of best before dates in this sector is vague because products reach consumers in a variety of formats: from bulk products, which are hung and sold by piece cutting, to pre-sliced consumer portions, which may be packed in modified atmosphere packaging (MAP), where a gas mixture are injected in the package. It would be interesting to extend the study of losses to non-specialized distributors and consumers. In addition to these highly stabilized products, there is a growing demand for less-processed products (less salted, less dried, softer texture). Such products require much better stability control, which largely relies on good control of the process (formulation, drying and preservation). However, the absence of a regulatory framework and the lack of infrastructures for product characterization and process monitoring are all threats to the sustainability of these new niche markets, which are nevertheless economically and socially promising. The formulation of biltong and the links between mass transfers and product properties such as texture, pH, water activity (a_w) and salt content were studied in the project. The aim was to develop a multi-criteria optimization tool based on a global process model. This simulator used simplified models developed at the unit operations scale for a better control of the end product quality in terms of reducing the variability of the finished products, improving storage conditions and extending shelf life by reducing yeasts and mould, while ensuring a sustainable technological route. Until now, only the tumbling operation had been modelled, which made it possible to identify the experimental solute profiles obtained in the meat, and thus, numerically, the diffusion coefficients for salt and acid during the tumbling formulation (Mirade et al., 2020). Further studies are under way to define the best salt and acid concentration profiles for post-tumbling in order to obtain, once the final drying operation is complete, a finished product offering the best trade-off between good stability and the organoleptic characteristics (e.g., tenderness, taste) that consumers want.

⏩ Loss and waste along fruit chains

Loss and waste percentages are generally higher for fruits and vegetables than for other products, especially in situations where cold storage or processing conditions are inadequate (FAO, 2019). Even in Western countries where cold chain facilities are well developed, the high fragility and perishability of fresh fruits and vegetables lead to considerable FLW, especially at the retail and consumer levels. Many innovative technologies were considered to extend the shelf life of fruits and vegetables and reduce their FLW. Although the link between food shelf life and losses is not straightforward or perfectly formalized, well-designed packaging can help preserve food and reduces FLW. In the post-harvest chain for fresh fruits, the use of equilibrium modified atmosphere packaging (known as eMAP[14]) could help extend the product shelf life and mitigate losses and waste along the supply chain, especially in consumer homes (Angellier-Coussy et al., 2013; Guillard et al., 2018). The project focused on exploring the link between shelf-life gain and loss reduction through eMAP, as well as the environmental benefit of using such packaging technology, either to replace or in addition to cold storage, which is currently the most-used preservation technology.

The objective was to develop a mathematical model for predicting shelf-life extension of strawberry and losses at the distribution and household stages. Stakeholder practices and beliefs, particularly those of consumers, were collected through intensive field surveys. Mathematical modelling integrated these consumer practices in order to predict losses at home based on the occurrence of each consumer behaviour: for instance, some consumers always store strawberries in the refrigerator, while others store them at ambient temperature; some consumers always open the pack immediately after purchase, which disrupts the modified atmosphere and thus

14. eMAP is a type of Modified Atmosphere Packaging (MAP), used more specifically for fruits and vegetables, that creates an optimal gas mixture in the closed product environment. The mixture of gases around the product is the result of product respiration and gas permeation through the film. Equilibrium between these two phenomena leads to an optimal gas composition around the product. Suitable gas composition can be achieved only if the gas (oxygen and carbon dioxide) permeation properties of the packaging film match the respiration characteristics of the product under set conditions of surface, package volume and fruit mass.

eliminates its benefit on fruit preservation. The environmental benefit of implementing eMAP in the post-harvest strawberry chain was also evaluated in comparison with the impact of refrigeration and considering the diversity of consumer behaviours. To quantify the gain in shelf life obtained using eMAP, a mathematical model was developed for predicting strawberry deterioration, coupled with mass transfers of O_2 and CO_2 into the package and fruit respiration. The level of deterioration depended on the temperature and CO_2 content in the package at equilibrium. This model allowed numerical exploration of storage conditions at different times and temperatures as well as prediction of the shelf-life gain for more than one day; as a result, significant benefits in terms of shelf-life gain could be expected for this product under eMAP (Matar et al., 2018a, 2018b). Matar et al. (2018a) calculated a 13% maximal acceptable deterioration based on consumers' readiness to buy and measured deterioration curves. In other words, if deterioration is less than 13%, the consumer will purchase the punnet of strawberries; if it is more than 13%, the consumer will reject the punnet, and then it will be thrown away by the retailer. Once at home, losses were considered as proportional to product degradation; this degradation depending on storage conditions (temperature and internal atmosphere composition under eMAP conditions and consumer practices). In order to evaluate the consumer practices, we conducted a consumer survey during the two last weeks of May 2016, during the strawberry harvest period. The survey was completed by 749 participants over 20 years old and representative of the French population in terms of age, gender, and occupation. Among other findings, 79% of consumers removed the packaging just after purchase. A total of 57% of consumers kept the fruit at ambient temperature, while 43% of them kept the strawberries in the fridge.

To account for the many post-harvest storage conditions and consumer practices that could reduce food losses, 132 scenarios for storage of fresh strawberries were investigated with the developed numerical model. These scenarios were used as inputs to calculate the losses generated in the post-harvest chain as a function of product deterioration. Considering the probability of occurrence of each scenario and consumer practices, the use of eMAP instead of commercial macro-perforated packaging would reduce losses by an average of 17%. The loss reduction is low because 50% of consumers open the packaging before storing the fruit in the refrigerator, thus disrupting the benefit of eMAP before the fruit is consumed. Losses might be reduced by 74% if all consumers stored the strawberries in the fridge with the packaging intact (Matar et al., 2020).

Finally, the life cycle assessment (LCA) method was used to address the environmental benefit of using eMAP at ambient temperature as an alternative to the use of conventional macro-perforated packaging and refrigeration. LCA was applied to the strawberry supply chain, from production to consumer level, considering losses at each stage as well as packaging production, disposal and usage benefit, if any, in terms of food loss reduction. Our findings confirmed that for highly perishable products such as strawberry, the production stage is the main source of environmental impacts. Accordingly, the preservation technology that minimizes losses has the lowest environmental impact in spite of its direct impacts. The main conclusions of this study are that eMAP could be, under various conditions, a valuable option compared to standard packaging strategies (Matar et al., 2020).

⏩ Smart design and application of innovative technologies to reduce FLW

FLW can be reduced in the future by using engineering approaches that combine the use of food degradation models and the smart design and application of innovative technologies that slow this degradation. This section details the different steps needed to reach that objective.

The need to develop representative food degradation models for better shelf-life evaluation

Extending product shelf life and reducing losses requires limiting microbial growth and enzymatic degradation at the surface of fresh products. In Western countries, the intensive use of cold storage and packaging solutions are traditionally used to reach this objective. Low O_2 and high CO_2 concentrations in eMAP reduced strawberry losses. Both the inhibition of microbial growth and the decrease of respiration and enzymatic deterioration were considered using a unique degradation mathematical model. In the case of red meat, MAP are used instead of eMAP. These MAP usually contain a high level of CO_2 to slow bacterial growth, as well as a high quantity of O_2 to maintain the attractive red colour of meat. To correctly predict food degradation, two different degradation models are needed to separately model microbial growth inhibition and the change in meat colour. Recent work has been done to connect the change in the red colour parameter to the oxidation-reduction potential during preservation of a piece of steak, stored either using an oxygen totally permeable package or a modified atmosphere package (MAP) totally impermeable to oxygen (Cucci et al., 2020). One can imagine using such a simple model and artificial intelligence algorithms to reduce losses in factories. However, this approach remains limited and cannot be applied directly to new processes, because the dynamic of the model is not yet fully explained. Another approach is to model oxygen diffusion and oxidation kinetics to predict the colour change of beef meat. These more fundamental models are under development, including complex reaction schemes (Tofteskov et al., 2017; Oueslati et al., 2018; Kondjoyan et al., 2022 a, 2022b). Within the framework of the H2020 GLOPACK project,[15] some MAP modelling tools are currently being upgraded and deployed to propose decision-aiding software in the field of food packaging. These models have integrated all mass transfer phenomena in the MAP of fresh produce and some degradation, such as microorganism growth. Even if the degradation models are still very elementary and do not provide a full overview of the reactions involved in a product's degradation, the software can be used to optimize MAP (atmosphere composition and selection of appropriate packaging materials) and avoid any loss of efficacy before the best before date. This tool has the advantage of being applicable on a wide variety of food products (dairy, meat, ready-to-eat foods), provided that the targeted optimal atmosphere for limiting degradation and optimizing shelf life is known. The more

15. https://glopack2020.eu/

fundamental models remain of interest to understand the effect of variation of food composition or treatments (cooking, etc.) on product degradation and to design new food products (Kondjoyan et al., 2022a, 2022b).

The need to clarify the benefit/cost ratio of innovative technologies for food loss reduction

Cold storage remains costly in terms of energy use and must be well managed; cold chain failures still occur, even in Western countries. To mitigate the overall environmental impact of the post-harvest chain, attempts were made for some fruits and vegetables to replace, either partially or totally, cold storage with eMAP technologies. Both technologies are designed to slow down product respiration and extend shelf life, but these effects still need to be quantified and compared. By reducing FLW, both technologies will generate environmental benefits. However, improved efficiency to reduce FLW does not automatically lead to environmental benefits. Some technologies that are used to reduce FLW may have their own impact on resources and greenhouse gas emissions, thus counterbalancing food loss reductions. This benefit/cost ratio is a key point for all innovations proposed to reduce FLW; however, it is rarely evaluated. Our research demonstrated that, in the specific case of fresh strawberries and for long-term storage (more than two days in consumer homes), eMAP at ambient temperature could not replace refrigerated storage. In spite of the additional environmental cost of cold storage, the costs were not high enough to offset the environmental benefit of reducing FLW. In several other conditions, eMAP could be a valuable option compared to standard strategies for strawberry storage. Our approach and methodology could be generalized to other food chains to better evaluate the efficiency of technologies for food loss reduction.

The need to quantify the efficiency of alternative food preservation technologies

Among innovative technologies used to extend the shelf life of fresh food and reduce losses, recent research has been dedicated to alternative methods of biopreservation or microbial inactivation and non-thermal physical processes. Biopreservation is based on known microorganisms or substances, but it is often limited by legislation on novel foods and by consumer aversion to biological or chemical additives. As a result, there has been new interest in non-thermal physical processes. The development of high hydrostatic pressure processing (HPP) can considerably extend the shelf life and limit losses of fresh products (Huang et al., 2014). However, HPP requires large, expensive infrastructures and is mostly reserved for high value-added products for exportation, large companies or regionally-funded platforms. Other non-thermal processes (NTP) have been studied to decontaminate fresh foods, extend shelf life and limit losses. Pulsed electric field, pulsed light, ultraviolet light and cold plasma are more acceptable to consumers than gamma rays or even X-rays (electron beams). Extending food shelf life is more efficient when the treatment is directly applied in the package, in homogeneous liquids, or on easily accessible flat surfaces. NTP effectiveness on solid food products of complex shapes, such as carcasses or meat pieces, is often lower and applications have so far been restricted to research. However, inactivating microorganisms on the food surface is not enough to preserve food, because biochemical reactions can also alter food sensory properties. Moreover, some microbial inactivation processes can promote these reactions in foods (such as HPP, which accelerates the oxidation reactions in red and fatty meats), and change their colour and flavour, thus increasing meat losses. It is therefore essential to better predict colour change according to oxidation. Moreover, the study of oxidation kinetics is of interest because these reactions generate the chemical radicals used in some non-thermal microbial inactivation processes. Further research is still needed to decipher the impact of these alternative technologies on food shelf-life extension.

The need for targeted actions to reduce food losses in the Global South

What solutions could be imagined to limit the loss of fresh products in the Global South where cold storage is not always possible, nor sustainable, and where expensive HPP regional platforms are not relevant or impossible to fund? One possibility is to move towards surface inactivation methods that combine simple and adaptable physical processes with the application of 'natural compounds', while using little energy and water. For example, low combustion energy and/or solar energy could be used to vaporize natural bacteriostatic or bactericidal compounds at temperatures of 75°C to 90°C. This technique is based on the ancestral principle of food smoking, but without smoke, mimicking recent applications of chlorine without the potential health risks (Sun et al., 2019). Many natural compounds with bactericidal or bacteriostatic effects have been proposed in Western countries (Tyagi et al., 2012), but many other compounds can certainly be extracted from flora found in the Global South. Another way to inactivate microorganisms on flat surfaces after cutting meat products could be the use of pulsed light involving ultraviolet light-emitting diode technology as proposed by Hinds et al. (2019). However, in the Global South, even if the surface of meat products has been microbiologically decontaminated, it is strongly recommended to treat the entire product due to the absence of cold storage, the dangers of recontamination, and the presence of parasites in animal muscles. The design of food processing systems in these countries is a complex activity driven by major health, economic, environmental and human issues, and it seems worth it in this case to develop efficient and sustainable locally-adapted transformation systems, based on traditional know-how but able to add value to food, including its nutritional quality, at affordable costs and with efficiency targets. Considering various performance criteria such as organoleptic characteristics, nutritional and sanitary qualities of the product, energy consumption, and environmental impact, as well as cost and system robustness, raises the question of how to prioritize them and determine how they should be aggregated for process optimization (Madoumier et al., 2019; Raffray et al., 2015; Rivier, 2017). For example, regarding biltong, the development of a multi-criteria optimization tool combining models developed at the unit operation scale could lead to a sustainable development of this product, satisfying consumer expectations in terms of less processed products while making it possible to identify the best technological pathways that limit product losses, especially during storage. Such a generic approach could be transposed to Western countries to design new food products and processing systems.

The need for an inclusive food engineering approach

A number of factors may prevent food supply chain stakeholders from taking fully rational decisions and adopting practices that would enable them to efficiently reduce FLW. In particular, food operators and consumers may have inadequate information on the options available for reducing loss and waste or the benefits of doing so. Indeed, our work highlighted the importance of consumer awareness and beliefs about technologies used to preserve food; for instance, French consumers habitually open packaged fresh fruit and vegetable products just after purchase, which leads to product respiration, thus disrupting any modified atmosphere and cancelling out its efficacy as a means of food waste reduction. Our work demonstrated that engineering modelling approaches could integrate consumer behaviours regarding food storage and consumption in order to explore and assess their impact on FLW reduction (Matar et al., 2020). It is therefore essential to improve awareness among individuals and convince them of the benefits of new technologies for reducing FLW. Additionally, stakeholders may also face constraints or preferences that prevent or deter them from implementing actions to reduce FLW. Knowing and integrating all these constraints in a more inclusive food engineering approach is key to designing technologies that align with stakeholder demands and practices. This issue is essential, especially in the Global South, where processing constraints are tricky. The biggest challenge for the future will be combining interdisciplinary forces, such as food science, food engineering and the social sciences.

⏩ Conclusion

A food engineering approach was proven to be efficient when considering how to reduce food loss and waste in meat and fresh fruit food supply chains. In Western countries, our study confirmed that a large part of fresh product loss and waste takes place in consumer homes, but that it is often due to problems that originate further up the chain. Mathematical models combining data on mass transfer and food quality can predict the share of FLW linked to food degradation. In the future, our results on combined models can be associated with smart sensors to improve processing and packaging design. Tailored, low-cost and small-scale preservation processes would be of paramount importance to reduce FLW in the Global South, where extensive use of cold storage is neither advisable nor sustainable. A tailored approach would require the implementation of a holistic approach for multi-objective optimization of whole food processing to be able to consider food safety constraints and new consumer expectations in terms of the sensory and nutritional quality of products as well as those related to processing sustainability. Finally, our work illustrated the importance of multidisciplinary approaches needed to evaluate the benefit/cost ratio of technologies to reduce FLW and deliver major societal benefits. Collaboration between the food science, food engineering, nutrition, environmental science, economics, and sociology fields is needed to carefully link the reduction of FLW and food security, market and consumer expectations, acceptances and practices, and environmental sustainability.

⏩ Acknowledgements

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Chapter 9

Artisanal palm oils: from quality design in southern Cameroon to consumption in Yaoundé

Sylvain Rafflegeau, Germain Kansci, Claude Genot

African countries are facing high population growth, rural exodus and heterogeneous economic growth. These changes are reflected in different ways: rising demand for food, which is supplied by local production and imports; more sedentary lifestyles; and dietary changes, with people eating more out-of-home meals and fried foods, and consuming a higher proportion of fats in their total calorie intake, more processed foods, and less fruits and vegetables. As a result, undernutrition has decreased but still persists, while rates of overweight and metabolic diseases are rising and protein, vitamin A and micronutrient deficiencies remain a main concern (Nansseu et al., 2019; National Institute of Statistics [Cameroon] and ICF, 2020).

African countries around the Gulf of Guinea are traditional producers and eaters of red palm oil (RPO). In these countries, oil and fat consumption is continuously rising as a result of economic development (Ambagna and Dury, 2016), but the younger generations show a tendency to abandon RPO for sociocultural reasons (Lamine, 2006). Meanwhile, the increasing use of palm stearin from refined palm oil by food industries has led to a growing controversy at the international level due to both the environmental impact of industrial oil palm plantations and the health consequences of frequent consumption and high levels of dietary saturated fatty acids. This controversy should be carefully weighed with regard to Africa where RPO consumption could solve health problems related to vitamin A deficiency (Engle-Stone et al., 2017).

In the southern regions of Cameroon where oil palm (*Elaeis guineensis*) is endemic, the production of artisanal RPO is rising due to the development of artisanal mills (Ndjogui et al., 2014; Rafflegeau et al., 2018). Used as an ingredient in various local dishes, the artisanal and industrial RPOs are sold on the markets to local consumers without any quality control for the artisanal RPO. However, a decrease of its consumption per capita has been observed in the urban area of Yaoundé. In 2001, RPO was reported to be the most-consumed oil by the population of Yaoundé, totalling 60% of oil consumption, 5% of household budgets and 10% of calorie intake for residents. In 2016, RPO accounted for 25% of the oil consumption and only about 20% of the edible oil market due to its lower price than refined palm, soya and cottonseed oils (Rébéna et al. 2019).

This chapter highlights the links between extraction conditions of artisanal RPOs in southern Cameroun and their physicochemical and nutritional characteristics. It also aims to identify the determining factors of consumer choice for specific RPO culinary applications in Yaoundé. The potential contribution (negative or positive) of RPO to nutritional intakes with regard to health issues and dietary trends is also underlined.

⏩ Characteristics of processed fruits, artisanal mills and production factors in the surveyed area

Over time, southern Cameroon farmers developed a deep understanding of how to manage the local wild *dura* palm. From the late 1970s, the African oil palm development plan named ‘plan palmier’ introduced farmers located near industrial mills to a new high-yield selected palms. This selected *tenera* palm, which produces 100% *tenera type fruits*, is obtained from selected *dura* × *pisifera* palms of different origins (Ndjogui et al., 2014). Farmers rapidly adopted this new selected palm, but they lacked information on its propagation: where to buy selected *tenera* seedlings or seeds and the reasons why they should buy them systematically. Curry et al. (2021) explain why without this propagation knowledge, farmers planted mainly open pollinated progenies, a mix of 50% *tenera* palms, 25% *dura* palms and 25% abortive *pisifera* palms instead of 100% selected *tenera* palms. Farmers located farther away from agro-industries adoped the selected tenera palms more slowly without any support from development projects. Meanwhile, non-governmental organizations promoted the artisanal extraction of RPO by training blacksmiths to replicate different models of small-scale presses (Poku, 2002). Nowadays in the whole palm oil production area, the outcome of these development efforts is a diversity of fruit types processed by artisanal millers, where every possible mixture of fruit types can be seen: 1) wild *dura* fruits with a very thin pulp layer and thick stone shell, 2) *tenera* fruits with thick pulp layer and thin stone shell, and 3) *dura* fruits with intermediate characteristics. Since palm oil is extracted from the pulp, the type of processed palm fruits is the main factor explaining the rate of oil extraction for a given extraction tool and process (Rafflegeau et al., 2018).

In 2015, we interviewed 32 artisanal millers from four production regions and described, for each artisanal mill, the processed fruits, the equipment and the processing conditions. The main technical factors differentiating these artisanal mills were the type of processed palm fruits, the production conditions from harvest to extraction and the type of extraction press, with characteristics varying from one region to another (Figure 9.1).

The survey revealed that the palm oil yield was the lowest in the West region where smallholders often processed wild *dura* palm fruits with water extractors. Using this method, one 200-litre drum of fruits yielded around 25 litres of RPO. In the other regions, the oil yield ranged from 40 to 60 litres per drum of fruits. These data confirmed the results of a previous survey conducted in 2000 (Rafflegeau and Ndigui, 2001).

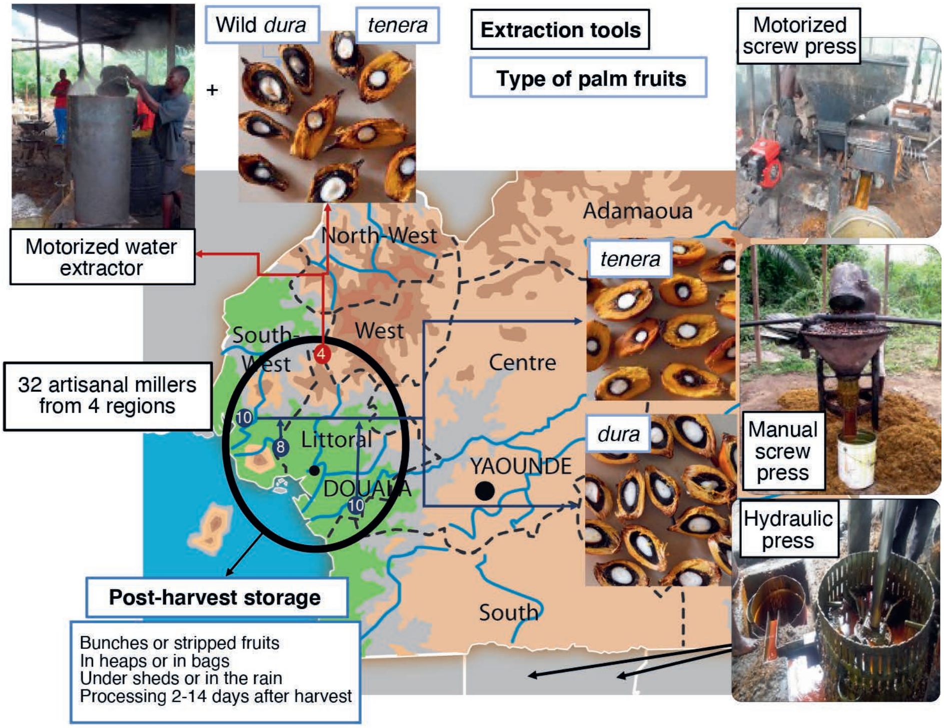

Figure 9.1. Main technical factors differentiating the palm oil artisanal mills in southern Cameroon.

In the Littoral and Centre regions, most of the artisanal millers processed *tenera* or a mix of *tenera* and *dura* fruits, generally harvested from their own plantations, with screw presses or hydraulic presses. In the regions located farther away from oil palm development initiatives, three out of 10 artisanal millers in the South-West region and three out of four in the West region processed wild *dura* fruits. Millers from the West region were the only ones to extract palm oil with motorized water extractors locally designed and machined.

As previously shown, the storage of bunches/fruits before extraction affects the oil extraction yield and the free fatty acid content in the oil. To facilitate stripping and increase RPO extraction yield, the 32 artisanal millers stored the palm fruits prior to extraction as bunches or as stripped fruits in a dry area or under the rain, either in bags or in piles. The time of storage varied between two and 14 days, at a temperature that depended on the season. This contrasts with the way industrial mills operate: they process bunches only from *tenera* palms, selected for their high oil content and harvested at their optimal degree of ripening, within 24 hours of harvesting. Industrial RPO processing meets international export standards.

Another parameter that plays a critical role in oil extraction yield is the temperature of the fruits entering the extraction press. A survey conducted in 2000 (Rafflegeau and Ndigui, 2001) demonstrated that this parameter displayed high variations depending on the artisanal mills and was a limiting factor. In 2015, all surveyed millers controlled this parameter, often reheating the fruits just before extraction.

⏩ Influence of processed fruit types and process parameters on the composition and quality of artisanal red palm oil

In the investigated area, the palm fruits processed by the artisanal mills were characterized by a considerable heterogeneity. This heterogeneity arises first from the types of planting material planted in oil palm smallholdings, second from cultivation conditions, and finally from harvest and post-harvest practices. The fruit ripening state when the bunches are harvested; their degree of damage (bruising) during harvesting, handling and transportation; and the storage conditions before extraction affect the activity of endogenous and microbial lipolytic enzymes (Nanda et al., 2020). During storage of the bunches and/or the stripped palm fruits, the activated lipases liberate free fatty acids from the oil triacylglycerols.

In line with the literature on the topic, after extraction at laboratory scale using a small manual screw press, selected *tenera* palm fruits yielded more oil (10 g to 16 g palmitic acid [C16]/100 g fruit) than *dura* fruits (about 8 g/100 g). The resulting palm oil was more fluid and less saturated (57 g/100 g fluid fraction versus 44 g/100 g for RPO from *dura* fruits), due to lower proportions of saturated fatty acids (about 51% total fatty acids versus 56% for *dura*), which included palmitic acid (45% versus 50%). RPO from *tenera* fruits also contained higher amounts of unsaturated fatty acids, mainly oleic acid (35% to 39% versus 33% for wild *dura* fruits) and linoleic acid (9% to 13% versus 9%). Interestingly, the RPO extracted from *dura* fruits contained more linolenic acid (1.5% versus 0.3% to 0.4% for *tenera*) and exhibited a nutritionally favourable omega-6/omega-3 ratio (5.7 versus about 32). The contents in lipophilic antioxidant vitamins, namely carotenoids (provitamin A: 690 mg/g to 730 mg/g) and tocopherols plus tocotrienols (vitamin E: 710 mg/g to 750 mg/g) was roughly similar for the tested fruit types.

The effect of the duration of post-harvest storage on oil extraction yield and their free fatty acid content is also well documented (Ngando Ebonge et al., 2011). We measured an increase in the oil extraction yield at lab scale (*tenera* fruits harvested in selected palms at La Dibamba research station), from 15 g/100 g fruit at day 1 to 29 g/100 g at day 9 (19 at day 5). Meanwhile, free fatty acid content (expressed as grams of palmitic acid/100 g oil) increased from 0.5 g/100 g to 9 g/100 g; this level is acceptable according to the current standards for commercial oils (<5%) until day five (2.5 g/100 g). We also observed a small decrease in carotenoid content (Nanda et al., 2020). Based on these results, we concluded that palm fruits can be stored at room temperature for three to five days post-harvest to facilitate fruit stripping, optimize oil yield during small-scale oil extraction, and preserve the oil quality. For storage times over five days, the risk of declining oil quality increases considerably. Storage in a dry place will also prevent mould growth.

We assumed that these palm fruit characteristics (i.e., fruit types plus storage time and conditions) directly influenced the composition and quality of the resulting crude palm oils. However, we were unable to correlate the fatty acid composition of the RPO sampled at the 32 artisanal mills to the fruit types sampled in the same artisanal mills. This is probably due to the heterogeneity of the processed fruit types.

Artisanal RPO contained roughly half unsaturated and half saturated fatty acids, regardless of the processing conditions or fruit types. In the unsaturated fatty acids (48.0% [g /100 g total identified fatty acids] to 57.3%, mean value: 51.8% ± 1.9), oleic acid content ranged from 36.5% to 46.6% (mean value: 48.2% ± 1.9) and linoleic acid from 8.5% to 11.1% (mean value: 9.8 % ± 2.7). Saturated fatty acids ranged from 44.9% to 51.9% (48.2% ± 1.9), including palmitic acid from 38.5% to 44.7% (41.4% ± 1.7). This composition gives RPO a semi-fluid texture, which is important in achieving the desired characteristics in local dishes. From a nutritional point of view, due to the molecular structure of the palm oil triacylglycerols, the saturated fatty acids (mainly found in external positions of triacylglycerols), are preferentially oxidized, which provides energy without being (or only weakly) atherogenic (Hayes and Khosla, 2007; May and Nesaretnam, 2014). Unsaturated fatty acids, among them the essential linolenic acid, are mainly found in the triacylglycerols' internal position and are thus fully bioavailable. Regarding micronutrients, RPO contained relatively high amounts of carotenoids (390–980 μg/g oil), which are absent from most commercially refined oils. Interestingly, the highest carotenoid content was observed for oils sampled in the West region, where motorized water extractors are used and mainly wild *dura* palms are grown. Carotenoids are what give RPO its orange colour. They display provitamin A activity, which is very important for the population in Cameroon, which suffers from vitamin A deficiency (Dong et al., 2017; Engle-Stone et al., 2017; Oguntibeju et al., 2009). The oils also contained vitamin E isomers (180–790 mg/g), mainly in the form of tocotrienols that, in addition to their antioxidant activities, exhibit anticancer and cardioprotective properties (Agostini-Costa, 2018). Importantly, all the RPOs exhibited peroxide value < 10 mEq active oxygen/kg (mean value = 2.8) corresponding to low oxidation levels and compliance with *Codex alimentarius* specifications (WHO, 2019).

The free fatty acid levels of the 32 RPOs ranged from 4.0 g palmitic acid/100 g to 35.1 g palmitic acid/100 g (9.0 g/100 g ± 7.3). Among the RPO samples, only 10 had a free fatty acid content of < 5 g/100 g; the majority (16 samples) had free fatty acid contents of between 5 and 10 g/100 g, and six samples had free fatty acid contents of more than 10 g/100 g, generally around 20 g/100 g. Only one sample reached 35.1 g/100 g. These samples corresponded to over-ripe fruits stored for 14 days, to loose fruits stored in bags for six days, or to fruits stored (three to six days) in bags under the rain. Free fatty acid content over 5 g/100 g is generally considered as detrimental for commercial oil quality and corresponds to the maximum level recommended by international organizations (WHO, 2019). However, it should be noted that free fatty acids do not present any identified adverse toxicological effects. From a nutritional point of view, it would be relevant to address the effects on postprandial lipemia and the metabolic consequences of the presence of high amount of free fatty acids in the bolus before any action of digestive lipase.

⏩ Supply and market practices for artisanal and industrial RPOs in Yaoundé

The RPO issued from industrial and artisanal mills reaches the final consumers in Yaoundé through a supply chain that includes transportation, packaging and possible blending of the oils in containers varying by volumes and material. This supply chain concerns the oil producers who sell directly to mills or in neighbouring markets (only for artisanal millers), and to wholesalers, semi-wholesalers and retailers located in Yaoundé's small shops and marketplaces (Figure 9.2).

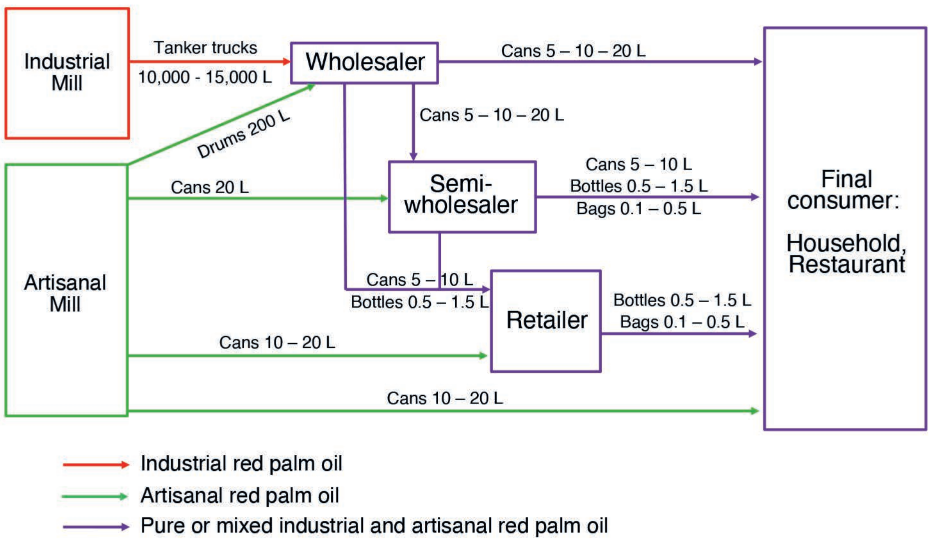

Figure 9.2. Red palm oil supply chain from industrial and artisanal mills to final consumers in Yaoundé (from Rébéna, 2016).

Sometimes wholesalers, semi-wholesalers and retailers mix artisanal and industrial red palm oils, so consumers are used to buying pure or mixed industrial and artisanal red palm oil .

The governement sets the wholesale price for industrial RPO (all taxes included XAF536 per litre in 2016), adding a 20% value added tax, while the price of artisanal RPO fluctuates with the season around an average price of XAF500 per litre without tax. Wholesalers appreciate the stable quality and price of industrial RPO, while they criticize the unpredictable quality of artisanal RPO.

Even if industrial and artisanal RPOs and their mixes have a similar appearance, the quality may vary widely. Wholesalers, retailers, sellers in small neighbourhood shops and the marketplaces, and buyers all use many different names to describe RPO: *huile rouge* [red oil], *huile artisanale* [artisanal oil], *huile industrielle* [industrial oil], and *huile de palme rouge* [red palm oil] are all generic names, but they offer little information about the characteristics of a given oil. Other common names include *huile Bassa* [Bassa oil, which refers to the Bassa people area], *huile Dizangué* [Dizangué oil, after the name of the town], *huile du village* [village oil], *huile Socapalm* [Socapalm oil, after the name of an agro-industry] and *huile Mulapalm* [Mula palm oil, also after Socapalm, which was selling under this trade name one litre bottled fractioned fluid RPO]. These names are mostly based on the origin of the oil, which is considered to be a quality criterion, but the definition and actual meanings implied by these names fluctuated significantly. Sellers have also their own specific vocabulary such as: *huile de premier choix* [‘first-choice’ oil], *huile de taro* [taro oil, because the oil is used in a typical dish made with taro] and *tête d’huile* [top oil]. Women and restaurateurs also use their own vocabulary: *huile brute* [raw oil], *huile traditionnelle* [traditional oil], *huile lourde* [heavy oil], *huile fluide* [fluid oil] and *huile pour la sauce jaune* [oil for yellow soup]. Despite this profusion of names, buyers and sellers agree on three main types of RPO based on their colour and texture (Figure 9.3).

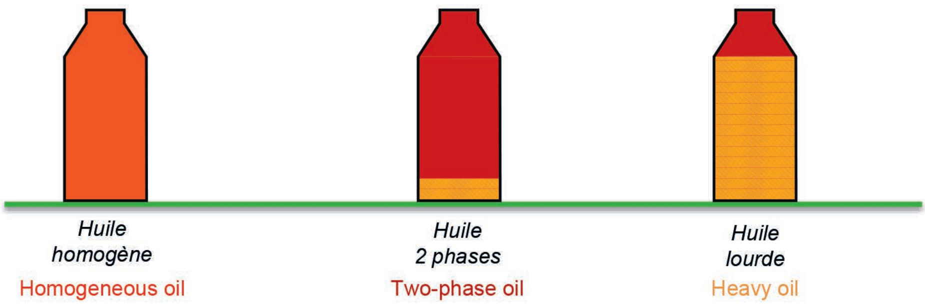

Figure 9.3. Three types of red palm oil are sold in markets and small shops in Yaoundé (from Rébéna 2016).

The homogenous oil is orange-red, slightly opaque and has a thick texture. The two-phase oil has a predominantly translucide, very red and liquid top phase and a small, opaque pale orange and semi-solid bottom phase. The heavy oil contains the same phases as the two-phase oil in reversed proportions .

The oil known as *huile homogène* [homogenous oil] is regularly shaken or stirred by the sellers in 200-litre metal drums to keep it from separating. Each buyer thus purchases a homogeneous portion of the RPO, rather than the top fluid phase of the container for the first buyers or the semi-solid bottom phase for the last buyers. Sellers may also divide the RPO into a mainly fluid RPO sold at a slightly higher price than the homogenous oil, and a mainly semi-solid RPO sold at a lower price. In absolute value, according to buyers, the price for homogenous oil and the two-phase oil varies by up to 100% according to the number of re-sellers and the oil quality.

⏩ Red palm oil: choice criteria, purchase strategy and consumption in Yaoundé

Consumers from Yaoundé buy artisanal palm oil in 20-litre cans directly from millers while travelling to the production area. They also buy RPO from wholesalers, semi-wholesalers and retailers in five to 10-litre cans, 0.5 to 1-litre plastic bottles or individual plastic bags in amounts depending primarily on their storage and cooking strategy, as well as their region of origin and standard of living.

Based on surveys conducted in 2016 of 124 households and 29 small restaurants in Yaoundé (Rébéna et al., 2019), our main findings show that:
– Consumers buy both artisanal and industrial RPOs (pure or mixed).
– They sometimes separate the oil at home into a more semi-solid form to keep part of it for certain dishes (for example, yellow soup) and the other, more fluid part for other uses.
– RPO consumption was found to decrease compared to previous surveys, but it always represented a significant part of the total consumption of edible oils (average consumption = 0.48 L/month/capita, representing about 34% of total consumption of edible oils).
– RPO consumption (from 0 to 3 L/month/capita) and uses vary considerably according to the socioeconomic profile and ethnogeographic origin of the surveyed women.

RPO purchasing criteria by end users are based on 1) the appearance of the oil: colour, texture, odour and taste; 2) the targeted use: consumers choose a more fluid or more semi-solid RPO depending on the dishes they want to prepare; 3) the trust buyers have in known re-sellers and/or in the oil's origin (e.g., the village where the artisanal RPO was extracted); and 4) oil price: for some buyers, a high-quality RPO is always more expensive.

Other criteria such as oil stability at high (frying) temperatures (an RPO that produces smoke upon heating is considered to be of poor quality), the freshness of fruits used for oil extraction and the oil composition are generally not available at small stores and market stalls.

Women and restaurateurs buy in decreasing amounts:
– Homogenous oil, with an average price of XAF690/L (XAF450 to 1000/L), whatever the region of origin;
– Two-phase oil, with an average price of XAF670/L (XAF450 to 1000/L), with a preference for consumers from the three northern regions;
– Heavy oil, with average price of XAF590/L (XAF500 to 750/L); consumers originally from the West, North-West and South-West regions preferentially buy this oil.

By comparison, the average market price for a one-litre bottle of refined palm oil fetches XAF1200/L.

Consumers buy RPO from semi-wholesalers when they want to stock up and from retailers for immediate use when they have run out. The higher the consumers' living standard and RPO consumption, the more they buy oil from wholesalers and artisanal millers in larger containers. People who have moved recently to Yaoundé (within eight years or so) maintain ties with their home village, where they often buy pure artisanal RPO directly from artisanal millers as a guarantee of quality. Large RPO containers may also be offered as a gift by family members still living in the home village. Women of Yaoundé who are originally from the three northern regions of Cameroon use less RPO than others, so they buy RPO for occasional use in small containers from retailers or semi-wholesalers. Consumers regularly purchase RPO from sellers they trust. Otherwise, when they do not trust the seller, they buy RPO in small containers to reduce the risk of buying poor-quality RPO.

The average RPO consumption of 0.48 L/month/capita would supply the provitamin A and vitamin E amounts recommended by international food security and nutrition or health agencies. However, RPO consumption is very heterogeneous depending on the region of origin of the surveyed women and regional food habits, ranging from 0 to 3.0 L/month/capita. RPO consumption is particularly low among the population originally from the northern regions of Cameroon, and who are the most sensitive to vitamin A deficiency in Yaoundé.

⏩ Red palm oil: a main ingredient in local dishes

Our survey provides evidence that women living in Yaoundé know an average of 3.8 cooking recipes (from 0 to 9) with RPO as ingredient (Rébéna et al., 2019). Women cook from 0 to 44 dishes with RPO per month (11 on average). The average number of recipes including RPO known by a given surveyed woman roughly reflects the average RPO consumption per capita for a given region of origin. It is the highest for surveyed women from the regions where oil palm is endemic. It is the lowest, both for the number of known dishes (2) and for dishes prepared with RPO per month (2), for women originally from the northern regions where oil palm does not grow. In contrast, an average of 16 dishes are prepared with RPO per month by the women originally from the Centre and North-West/South-West regions (Figure 9.4). These results illustrate the huge diversity between surveyed women.

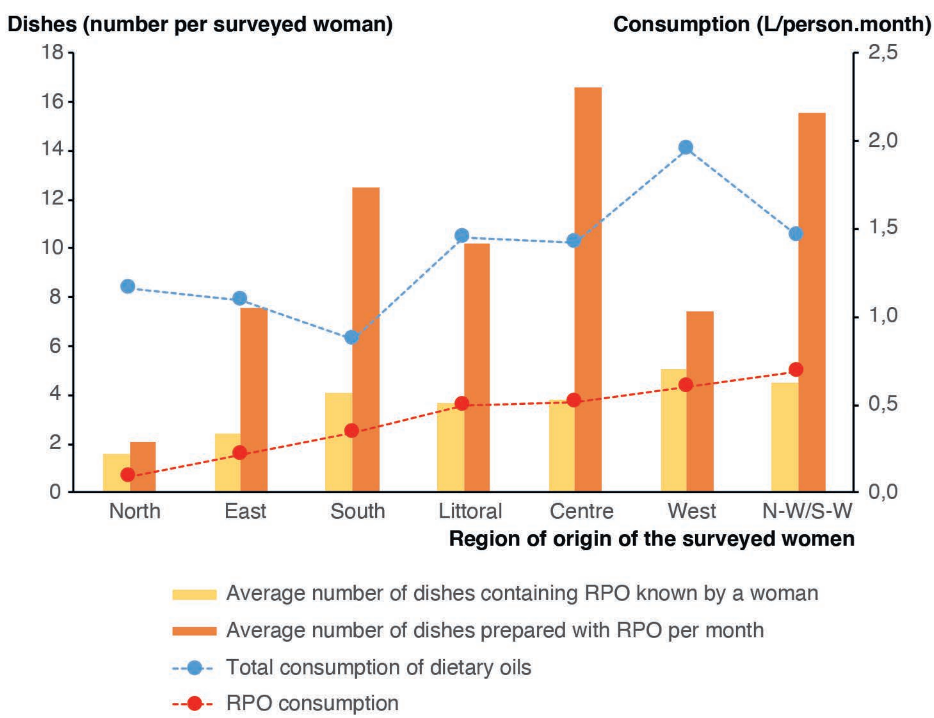

Figure 9.4. The use of red palm oil (RPO) by Yaoundé's women according to their region of origin.

The women surveyed who were over age 46, those born in Yaoundé and/or those belonging to households with 10 to 16 people declare the highest monthly per-capita consumption of RPO. The reason for this use in large households is budget-driven, since RPO is much cheaper than refined palm oil. The youngest women consume less RPO than their mothers and tend to replace RPO with other oils.

Women of Yaoundé are used to cooking with RPO, refined palm oil, or a mix (Figure 9.5). Some of the women heat RPO at a high temperature until its colour becomes lighter. This treatment degrades carotenoids and other antioxidants, causes losses of essential fatty acids and produces toxic neo-formed contaminants. This RPO, called *huile blanchie* (bleached oil) is prepared and used when the heavy colour of RPO is considered to be detrimental to the appearance of the dishes (mostly for frying and in sauces).

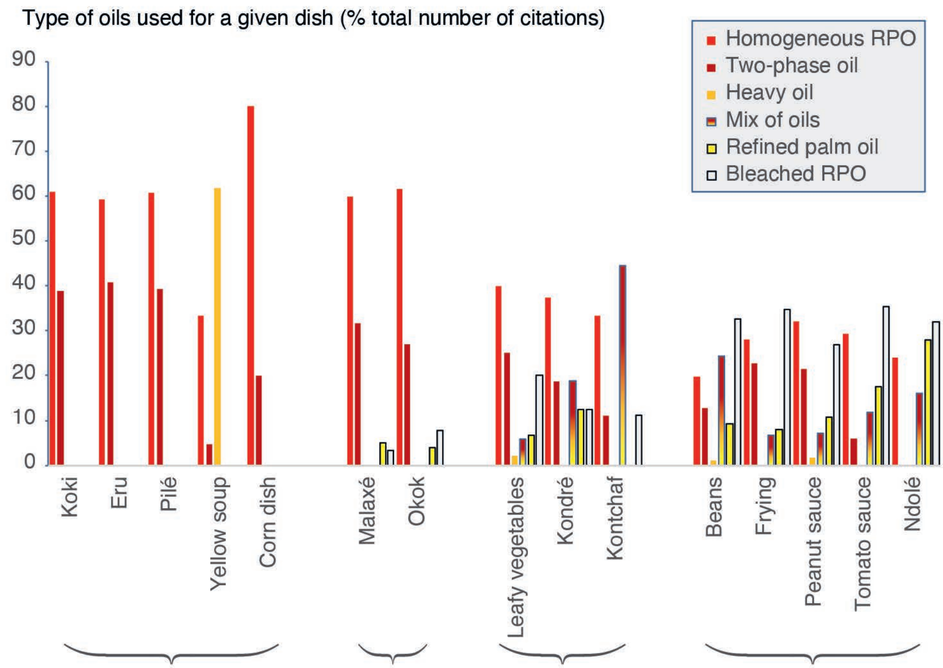

Figure 9.5. Uses of red palm oils (RPO) for cooking and importance of RPO in dishes: percentage of the different oils cited to be used to prepare a given dish (modified from Rébéna, 2016).

RPO has a different status as an ingredient in dishes (from left to right): it may be irreplaceable for some dishes, replaceable if necessary for others, appreciated but replaceable for others, or only as a substitute for another preferred oil.

Three main drivers explain households' uses of refined palm oil and RPOs. First, households follow traditions by reproducing their family cooking habits. Second, they consider the oil's culinary properties: taste, colour (a red or yellow colour is desired) and texture (a dish cooked with RPO needs to be hot enough to keep the sauce fluid; a good yellow soup depends on the RPO being able to stabilize the foamed emulsion). Third, the choice is economical because RPO costs half as much as refined palm oil, with the heavy oil type being the cheapest. Price leads consumers to separate and bleach RPO at home to produce bleached oil when the red colour is not desired.

High levels of free fatty acids in RPOs and the presence of the semi-solid phase help the oils form stable emulsions and contribute to the popularity of local dishes such as yellow soup. Free fatty acids contribute to the oral detection and sensory characteristics of fats (Poette et al., 2013) and thus participate in the typical taste of local dishes. A panel has recently evaluated versions of yellow soup prepared with RPOs with different acidity indices. The panel preferred the dishes prepared with the oil presenting the highest acidity index (about 16 mg KOH/g oil), corresponding to free fatty acid content around 7 g palmitic acid/100 g oil). However, a maximum acceptable level was not determined.

⏩ Conclusion

In this chapter, we explored the artisanal palm oil sector in Cameroon and highlighted links between the tools and practices of artisanal millers, the physicochemical and nutritional characteristics of red palm oil (RPO), the RPO distribution chain, and purchase criteria and cooking uses by consumers in Yaoundé. Our work provided evidence of a sector that includes a large variety of actors, processes, marketing conditions, types and usages of RPOs. The development of this artisanal sector could be an opportunity for the local development of small-scale entrepreneurship with economical, nutritional and anthropologic benefits including the preservation of local cultures.

One main conclusion is that, whatever the type of RPO, it is of nutritional interest for all local consumers because of the provitamin A content, a micronutrient for which deficiencies exist in Cameroon. Artisanal RPO is also characterized by a balanced fatty acid composition. RPO consumption should thus be promoted in the whole population, with specific messages targeting those who do not traditionally use this oil, i.e., those originally from the three northern regions of Cameroon and the younger generations who have tended to abandon its consumption. Simple and affordable recipes could be also disseminated among these populations.

RPO is of culinary interest for traditional African dishes in which it is irreplaceable due to its typical taste, colour, flavour and texture (Lamine, 2006). The artisanal RPO often contains levels of free fatty acids that are higher than current international standards, but these high levels likely participate in the characteristic and desirable flavour and texture of typical dishes such as yellow soup. However, to limit free fatty acid content in the oils to acceptable levels, avoid loss of vitamin E and A in RPOs while maximizing oil yield, and making fruit stripping easier, recommendations should be made to artisanal millers to process the fruits within five days of harvest and to store the bunches or fruits in dry conditions, or within three days of harvest to obtain red palm oil with free fatty acid levels that meet international export quality criteria.

The diversity of planting material and resultant types of palm fruits (*tenera* and *dura* from selected seedling to wild *dura* fruits and their mixtures), and of oil extraction conditions leads to production of artisanal RPOs with a large range of sensorial and culinary properties. One major challenge faced by end users of RPO (women and restaurant owners) is the lack of information about the quality and usages of the different RPOs present on the market.

There is a need to support the operators of the artisanal RPO sector through control of production and marketing circuits in order to promote market segregation of different qualities and labelling of RPO. Segregated quality RPO types could emerge from the clear identification of new oil quality criteria based on objective data, local names and/or commercially recognized labels, and display of recommended uses (for example 'heavy oil' is the recommended RPO for yellow soup). The optimal characteristics (e.g., processed fruit types, free fatty acid content, liquid-to-solid phase ratio) and processing conditions to obtain a RPO suitable for the preparation of specific culinary dishes still need to be defined.

Going forward, some key points should be addressed:

– the environmental impacts specific to artisanal RPO production: deforestation associated with artisanal mill expansion (Ordway et al., 2019), use of agricultural inputs (low), water supply and use of biomass energy (firewood, fibres, nut shells and sometimes kernel nuts), effluent treatment (non-existent in artisanal mills but available in industrial mills)

– productivity: loss of a third of the oil not extracted due to poor oil extraction rate, potentially lost co-products (part of the kernels nuts) and by-products (part of the fibres and nut shells)

– social and working conditions, labour health and safety

– food safety: evaluation of contaminants from the environment or from processing and packaging (neo-formed compounds, compounds from materials in contact with the oil)

⏩ Acknowledgements

We are deeply grateful to the millers, retailers, women and restaurateurs who kindly accepted to participate in our surveys. We would also like to thank the University of Yaoundé I for the use of its facilities as well as the permanent staff and students from all institutions who were involved in the project.

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Section V

Agroecology to promote resilient food value chains

Chapter 10

Neither quite the same nor quite another: diversity, identity and resilience in agroecological transition

Genevieve Teil, Sylvie Lardon

The general understanding of sustainability is quite restrictive and mostly deals with the exhaustion of resources and raw materials. This article adopts a more global view by focusing on the role of diversity in the resilience or perpetuation of a production activity. Though guided by the empirical evidence from two field projects, this article is more an invitation for thought than a detailed field report.

Diversity is a desirable trait in ecology; it is even regarded as warranting ecosystem sustainability. Ecological systems that are not sufficiently diverse are considered fragile: since they are unable to reorganize as a complex system in order to adapt, they are overly sensitive to lasting or unexpected changes.

Surprisingly, the analysis of economic systems reveals quite the opposite pattern. According to Karpik (2007), singularities – i.e., the existence of a large variety of significant diversities within the same category, such as for wines, restaurants, lawyers, physicians, movies or novels – remains unconsidered in economics. Neo-classical economics, which has focused on the conditions of fair competition, has essentially stressed the role of information on quality for the sound identification of homogeneous categories of products. The diversity of goods is justifiable only to the extent that it allows for better adjustment of products to consumers' subtle and diverse 'expectations' and 'preferences'. Additionally, diversity is always limited by the costs and the complexification of the consumers' choices it induces.

The analysis of geographical systems is less clear-cut. Studies on the resilience of territories highlight the importance of both territorial anchorage and local identity and know-how on the one hand, and on the other, openness to other territories and identities, the connection between different territorial scales, and actors' transformation and innovation capacity (Gasselin et al., 2021).

Are diversity *or* identity two possibly antinomic keys to ecological *or* economic resilience – that is, the capacity to last and perpetuate? This chapter investigates this question, drawing on two international[16] research projects carried out as part of the GloFoodS metaprogramme by CIRAD and INRA from 2015 to 2017. The first perspective is socioeconomic and draws on a study of cheesemakers' denunciation of the standardization of cheesemaking brought about by health standards, particularly milk pasteurization. The second perspective is geographical and explores hybridization, an original form of articulation of identity and diversity to adapt to changes within territories (Gasselin et al., 2020). In both cases, resilience is analysed not as the consequence of an intrinsic or acquired strength, but rather as the outcome of regimes of action with their own calculation devices, forms of organization and resources.

⏩ Pasteurization, a technique for control and optimization

The spatialized character of the economics of dairy production and processing was stressed long ago. Once milk has been drawn, the bacteria that grow in it acidify it and make it unfit for consumption. Dairy farmers are thus forced to establish themselves close to places of consumption. Various cheesemaking processes[17] allow them to get around these constraints and to set up in areas with less land pressure, provided cheese is processed locally (Vatin, 1997). Yet, the same problem arises when an operator decides to collect milk for cheesemaking, as the latter must take place quickly, before the milk bacteria multiply too much, causing the milk to curdle. The geographical scatteredness of farms and the speed of transport has determined the concentration of cheesemaking within cooperative or industrial dairy organizations.

In 1810, Nicolas Appert showed that heating milk improves its conservation. The partial sterilization that ensues allows the milk to be kept longer and therefore makes it possible to collect milk from a wider catchment area. Still, local microbial ecosystems are a major source of milk diversity, which is erased through their partial destruction. Milk heating techniques, particularly pasteurization, thus offer two benefits regarding the industrialization of cheesemaking: economies of scale and a greater control over production thanks to milk homogenization.

To compensate for the destruction of a good part of the flora needed to make cheese, it is necessary to culture the milk with microbial strains grown specifically for that purpose, and especially to mature the cheese. This technique has the major benefit of greatly increasing control over the cheesemaking process; the spreading of pasteurization over the world during the first half of the twentieth century has not only supported the industrialization of cheesemaking, but also the emergence of an industry for cheese culture production. The high uniformity of the resulting production makes it possible to base the product's identity on its regularity. This has fostered a particular marketing strategy: for the customer, the industrial product is guaranteed to match its particular identity.

Traditional on-farm cheesemaking, which does not put such emphasis on large-scale production optimization, uses other techniques to control the production process that involve the milk's microbial ecosystems. Subculturing, which consists

16. The projects' fieldwork included France, Italy, Australia, Brazil, Morocco and India.

17. Milk can also be turned into butter, as in Brittany, France.

in taking a little bit of the whey from the previous day to culture the next day's production, helps to maintain the milk flora and limit its variation, as do the wooden instruments that facilitate the development of the cheese floras and ensure their re-culturing from one batch to another. The maturing cellars are then home to complex microbial ecosystems that help to guide and control the ageing of cheese. Finally, the maintenance of processing facilities precludes any aggressive cleaning, so as not to destroy the ecosystems that ensure the final quality of the cheeses. The sensitivity to environmental conditions of ecosystems fosters diversity within production areas. Maintaining the ecosystems in this way also allows for seasonal changes, particularly within a same farm. In face of the hard competition driven by industrial firms, traditional cheesemaking has progressively contributed to the development of another commercial regime, which does not ground upon a strict stabilization of quality.

The coexistence of these two forms of organization of production has been disrupted by the gradual tightening of food safety standards. In some countries, particularly the United States and Australia, cheesemaking using raw milk has been banned[18] except for cheeses that are matured for more than 60 days, after which time the development of pathogens is no longer considered a risk. For cheeses matured for less than 60 days, in addition to heating the milk, the standards require drastic control of any potential source of contamination. Subculturing, which does not allow for a strict separation of batches, is prohibited. Requirements for cleaning procedures have become more stringent and all manufacturing processes using materials that are difficult to clean, namely wood, are prohibited; stainless steel and plastic must be used instead. As more international trade agreements have been passed, these standards have spread to other countries such as Brazil, where, as Ferreira and Ferreira (2013) show, the wooden boards on which cheese curds were once drained have been replaced by a slate table that upsets the production process and alters the taste of the cheese.

The ban on raw milk has long been the subject of international negotiations at the World Trade Organization (WTO), but the European Economic Community has opposed it (ECC, 1992), at the cost of adopting HACCP[19] rules and stepping up sanitary tests to screen for pathogens such as *Listeria, Salmonella* and *Staphylococcus aureus*, the tolerance thresholds of which have continuously been reduced. It is therefore understandable that 'raw-milk' cheesemakers have grievances about the strict sanitary standards ruining their microbial know-how. They are calling for this sanitary pressure to be lifted, arguing that not only is it not suited to their production system but it is also counterproductive. Montel et al. (2012) have thus shown that traditional techniques, particularly wooden instruments, are in fact not gateways to contamination and pathogens, but excellent bulwarks against *Listeria* in particular.

We should, however, not be too quick to assume an opposition between a rationalized industrial production and a declining traditional artisanal one leading to approximate quality and safety[20]: the two articulate homogeneity and diversity differently.

18. The ban on raw milk started in the 1920s in Milwaukee and extended progressively to other countries. It became effective in all US states by 1987.

19. Hazard Analysis and Critical Control Point: a risk prevention and defect traceability technique.

20. Montel et al. (2012) have thus shown that traditional techniques, particularly wooden instruments, are in fact not gateways to contamination and pathogens, but excellent bulwarks against *Listeria* in particular.

The industrial stabilization of the consumer-product adjustment

Has cheese diversity disappeared in countries that have made pasteurization compulsory? Like Buridan's ass in the work of Cochoy (2002), how could one not be struck by the extreme differentiation of the industrial production on US or Australian store shelves! The variety of ripening cultures is indeed limited, but it structures the international production around a few types of cheese that combine three main families of milk – cow, goat and sheep – with white-rind or washed-rind soft cheeses, cooked and uncooked pressed cheeses, and blue-veined cheeses (i.e., blue cheese). In each category, the differences tend to be concentrated downstream of production: ageing time, added aromatic ingredients (pepper, capsicum, spices, etc.), and variations in presentation (blocks, cuts or individual portions); as well as, of course, the marketing tools to stimulate the demand for cheese.

The differences between products relate to a set of criteria enabling the stabilization of each product's identity (namely strict definitions of the flavour, texture and aspect of the product) on one hand, and the stabilization of demand for that particular product identity on the other. Quality conformity is the keystone of industrial production, as well as the stabilization of customers' expectations thanks to sophisticated marketing techniques.

Still, this stabilization contends with multiple sources of variation. The raw dairy material, which is always fluctuating, is homogenized through the fusion of the catchment area's different sources of supply, pasteurization, and ultimately a strict control of key physicochemical characteristics. With regard to cheesemaking, stabilization also involves the artificialization of processing thanks to controlled cultures. Raw material homogenization is not sufficient to ensure the conformity of the end product and requires a final tuning. Additionally, some variations, either unexpected or resulting, for instance, from new standards or lasting changes in the raw materials or cheesemaking processes, cannot be homogenized and are instead compensated for. Doing so requires resources, that is elements of the product which are not part of the product's identity and do not affect the customers' direct experience. The production process is crucial for this final adjustment and thus kept as free of constraints as possible, so that the end product can be made consistent with its identity with the least possible losses.

Consumer habits are also not set in stone, and are carefully monitored using a range of demand-monitoring marketing instruments. In the event of ongoing or expected developments, like a rising rejection of fat or salt, the organization of production triggers an adjustment process, which aims to preserve the stability of the product-customer adjustment.

Finally, the industrial standardization process is a highly reactive, dynamic process of continuous stabilization of the relationship between a product identity that is stabilized but not frozen in place, and closely monitored consumers' attachments, thanks to products' homogenization techniques and crucial compensation resources.

The alternative management by artisanal cheesemakers

The artisanal organization of cheesemaking involves a completely different identity and diversity management system, which is far less cumbersome and costly. It is based not on the stabilization of production and demand, but on supporting and promoting product diversity.

Variability is part and parcel of small cheesemakers' everyday lives. Just as cooks adapt their recipes to the products delivered each morning, cheesemakers adapt the cheese they make based on the daily specificities of milk, the weather conditions or the draining of the curds. The control of this variability has fostered major controversies in areas with protected designations of origin (PDO).

PDO specifications relate both to animal breeding and milk processing into cheese and their authorized practices, and a series of characteristics of the end product, usually with regard to aspect, texture and flavour characteristics. Some producers support an evolution of the specifications in line with the industrial regime, towards reinforcing the definition of the end product. They demand the PDO name to work as a brand and a promise of conformity to a set of predefined characteristics, namely flavour. Simultaneously, they are also asking for the constraints on the production process to be relaxed in order to increase the resources necessary to comply with the more restrictive definition of the end product. Their opponents are requesting the reverse: a reinforcement of the processing constraints, in order to guarantee the 'authenticity' of the product, and the loosening of the end product identity, in order to open the search for the best quality. For the producers in the first category, variability in the end product is a hindrance to marketing the product. For those in the latter category, who often call themselves artisans or even artists, the quality promise attached to the PDO should focus on the acceptable resources that guarantee the authentic identity of the product; its variable quality expresses the skills of the producer, the terroir or a natural quality, as the case may be.

Cheesemakers all like to quip that *they* are not the cheesemakers, but *the microbes* are! Without microbes, there is indeed no cheese. But microbial life is particularly sensitive to many small variations in the composition of milk, particularly its temperature. Moreover, due to the rapid multiplication of microbes, the duration of the different stages of cheesemaking has a strong impact on the final cheese. Depending on the interpretation of the PDO guarantee, microbes may thus be major troublemakers, which need to be strictly controlled while monitoring the product's conformity, or a key resource in the search of product's quality. The divergence regarding the PDO guarantee goes along with the development of an alternative product marketing approach. Product variability is valued through marketing that is specific to this artisanal system, i.e., specialized shops, direct sales and most of all clients, namely amateurs (Teil, 2021), who value products' diversity, because it fosters their exploration of the product (wine for instance), which stands at the heart of their passion. Their choices are not grounded on rigid taste criteria and are open to new experiences. Here, the sustainability of commercial activities appears to depend less on stabilized consumers' expectations and product identity, and to be more permeable to biological changes and climate transition.

The tightening of health standards, which impoverish the microbial ecosystems of milk and disrupt its equilibrium, is particularly destabilizing for artisan cheesemakers. These standards limit the variability of cheese products and thus the expression of nature and cheesemakers' skills and specificities (cheesemaking techniques, terroirs, etc.). They also contribute to minimizing the difference between the industrial and artisanal regimes of production and commercialization. The vast majority of artisanal cheesemakers have, in fact, gradually been forced to make up for the microbial poverty of the milk by supplementing it with ripening flora similar to those used in industrial production.

Identity, diversity, sustainability

The denunciation of health standards by artisanal cheesemakers is not a plea for greater heterogeneity in production, but rather for a different articulation of diversity and identity. To exist, a being must at the same time achieve to be identifiable, that is, to be 'something', in order to interact; yet, to make this identity last, it also has to be able to transform in order to adjust to the multiple changes constantly arising. Resilience is not immobility; conversely, it is not a perpetual metamorphosis either. Sustainability builds on two legs. The two above market regimes each ensure the sustainability of production in the face of change, in different ways.

The industrial organization emphasize a product's characteristics associated with customers' expectations, which both marketing and production endeavour to make as stable as possible. The cheesemaking process absorbs changes, for instance in raw materials, standards or the production apparatus itself, in order to preserve the product's identity. Changes in demand are monitored to promptly and smoothly adjust production. The resulting succession of small changes allows the product endowed with a strong identity, to still being able to change and adapt.

On the artisanal side, an increase in cheese variability is not achieved at the cost of identity: the existence of the product does not vanish in an uncontrolled set of realizations. Identity is shouldered by the cheesemaker him/herself, the PDO name and specifications, terroir or nature, which allow for a much looser framework leading to acceptable variability of production.

Finally, health standards are the source of a surprising short circuit in cheese manufacturing, where industrial and artisanal regimes coexist. Pasteurizing and heating milk are fundamental instruments for creating economies of scale and controlling the quality of industrially organized production. Used as a sanitary standard, they deprive artisans of their microbes and standardize their production. In order to recover this resource required by the artisanal regime, artisan producers are calling for sanitary standards to be adjusted to the specific characteristics of the artisanal regime, particularly to the microbial ecosystems responsible for the specific diverse quality of their products. A growing number of PDOs thus makes it compulsory to use indigenous microbial starters, to strengthen the milk flora while safeguarding the particular typicity of artisanal products.

⏩ Diversity of organization forms in territorial development

Agricultural and food activities are changing as new development models (e.g., polarized, endogenous or distributed development) emerge (see Albaladejo, 2009), with calls for new forms of territorial adaptation at different organizational levels, from farms to regions.

Hybridization of territorial organization forms

Hybridization is one form of adaptation; it is both a factor of adaptation and also a result of the adaptation process itself (Lardon, 2021). In hybridization, a new form of organization is created through the combination of various elements inherited from previous forms of organization. Hybridization is carried out by certain actors who invent their own strategies to address challenges and engage in innovation and learning processes. These hybridized actors are pivotal to collective actions, such as a regional nature park (Amblard et al., 2018), and contribute to territorial development by connecting different scales and models, from local to global, to achieve an overall coherence (such as the articulation between the Livradois-Forez Regional Nature Park and the city of Clermont-Ferrand, France, for agricultural territorialisation; Lardon, 2015). Analysing adaptation of agricultural and food systems in different territories requires understanding adaptation as a process, and therefore studying the evolution of these systems as an adaptive capacity of forms of organization and as the result of territorial transformations. The 'actors-activities-spaces' model developed in geo-agronomy (Lardon, 2012) allows stakeholders to understand territorial dynamics and take actions to control them. The different dimensions of territorial integration involve the linking of spaces, combination of activities and coordination of actors to meet the challenges of a territory. This frame of reference sheds light on the complexity, transversality and flexibility of the systems studied and their representations through the analysis of socio-spatial configurations.

The territories studied are described through the lens of their socio-spatial configurations, looking at both their spatial organization and social relations (Lardon, 2015). These configurations offer insights into the development processes but also activate new models of territorial development. They are considered from a dynamic perspective to understand the potential and the capacities of territorial development.

Diverse socio-spatial configurations

Several case studies analysed in the FORMAT project show the diverse paths for territorial organization. They also reflect the forms of hybridization designed by stakeholders to adapt to changes and ensure the survival of their systems, such as new demand from consumers for food systems.

Tracing the evolution of the agrifood sector studied, which involves about 20 cattle breeders, a dairy and a supermarket in the area of the Livradois-Forez

Regional Nature Park in the Auvergne-Rhône-Alpes region in France, reveals the hybridization of the actors' strategies (Baritaux and Houdart, 2021). Working with milk from 'hay-only' operations, the sector produces two PDO raw-milk cheeses (Bleu d'Auvergne and Fourme d'Ambert), sold in Carrefour supermarkets under the brand 'Engagement Qualité Carrefour' (*Carrefour Quality Commitment*). For the cattle breeders, the hybridization takes place through the coexistence of production practices that are more akin to those of an alternative farming system (organic farming, no silage, feeding the cows only grass or hay, barn drying) and distribution practices typical of the industrial model. For the dairy actors, forms of hybridization can be found in the modes of valorization of regional products with the offer of PDO products, on the one hand, and in the standard products sold under their own brand or a supermarket brand, on the other. The distribution networks involved are therefore also hybridized. For the farmers, this is a way to better valorize the milk and secure their operations. For the dairy actors, this is a way to diversify outlets and secure a share of sales, as well as part of the supply through contracts to meet Carrefour's specific demand. For the supermarket, hybridization is a way to respond to competition and changes in consumer demand. All these forms of hybridization reflect the stakeholders' adaptation strategies to meet economic objectives and maintain their agrifood activity.

The marketing strategies of peri-urban farmers on the plain of Pisa, Italy, rely on the share of their total production sold locally through alternative and local distribution networks (Filippini, 2021). Farmers combine both traditional and alternative modes of production and commercialization to meet new demands from consumers looking for different food products. These peri-urban farmers are adapting to the new possibilities of geographical proximity to urban areas by hybridizing not only the forms of organization of local sales networks, but also their relationships with different marketing actors, both local and territorial. They cultivate relations with processing units, retailers and consumers at local and territorial levels, as well as institutional actors who play a role in the recognition of the urban food system. The sustainability of the different initiatives depends on several factors, although mainly on the maintenance of the balance between the urban and rural environment, opening up the territory to outside and coordinating the different supply chains involved.

Building a territorial identity that makes sense for the involved actors

The resilience of territories highlights not only the transformational capacity of territorial actors, their sense of belonging to a territorial identity and their openness to other territories, but also their territorial anchorage, their capacity to innovate and their traditional foundations (Iceri, 2021).

Thus, in the traditional community of Faxinal Emboque, in Parana (Brazil), local independent farmers are innovating by opening up to the outside market, with a view to maintaining their traditional know-how and becoming well anchored in the area (Figure 10.1). In order to maintain their product diversity and above all their autonomy, the actors of Faxinal Emboque target local and regional markets, on site or elsewhere, including public and/or private markets and via civil society networks. However, they do not comply with all requirements of traditional markets: their strategies aim to adapt to the market, so as to sell on a local and regional scales, and introduce changes to the market itself, through the mobilization of consumers and public policies.

Unlike neighbouring communities, the farmers of Faxinal Emboque have engaged in a process of development, innovation and adaptation by adopting an industrial sales and commercialization model through innovative strategies. This primarily involves a strategy to develop the sale of local products, through access to local markets and industrial outlets, while maintaining traditional and agroecological production practices in pig farming and maté harvesting.

Members of the community have taken the initiative to seek new actors to facilitate access to local and external markets, and to enhance the valorization of local resources and access to industry. They are thus taking advantage of their recognition by the Ministry of the Environment to facilitate their search for external partners and funding.

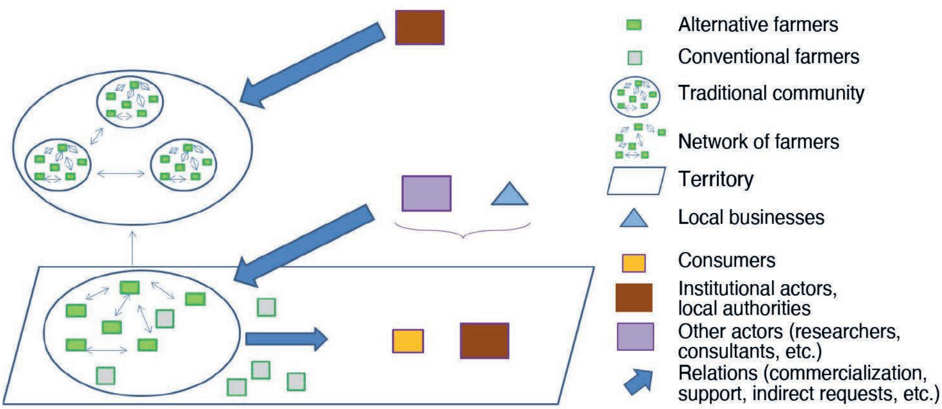

Figure 10.1. Socio-spatial configuration of the Faxinal Emboque community in Brazil.

The adaptation strategies of the Faxinal Emboque community rely first and foremost on the development of their socio-professional network through the active search for funding and partnerships with new actors outside the community. In particular, actors from the research community are helping them to improve their breeds and their production, while civil society organizations handle the commercialization of local products in long supply chains. Secondly, these strategies involve initiating changes in their farming systems to enhance the quality of their products, while still operating within a traditional or even alternative farming system. These farmers have maintained their strategy of diversification of production and sources of income and their role in the area's forest resources by introducing new products (candied pork, maté soda and ham) and expanding their outlets.

This hybrid approach has enabled the Faxinal Emboque farmers to initiate the development of the community's socio-professional network in order to develop their local production and products. The community is opening up to new products, new actors and new forms of organization without losing its identity by combining territorial anchorage and openness to other territories, with a traditional base and a capacity for innovation, in a socio-spatial organization (Iceri and Lardon, 2018) that is 'common' (Ostrom, 2009).

This form of organization, which connects scales from the local to the global level and combines traditional and industrial models to better innovate in a territory, is nourished by different territorial development challenges: maintaining and securing farming operations, strengthening traditional practices to secure the forest, developing collective projects, disseminating know-how and knowledge (cooking, gardens, etc.), and bringing recognition of individual and collective 'talents' of the involved actors.

⏩ Conclusion

Resilience is often analysed from the perspective of capacities of beings or characteristics of systems of beings, such as the diversity of ecosystems in ecology, the homogeneity of goods in economics or the plurality of forms of organization in geography. The cases we studied offer a different pragmatic understanding of resilience: it is no longer the more or less predetermined effect of intrinsic qualities, but the always uncertain result of an activity and effort to continue to persist, which relies on a number of instruments, know-how, collectives and methods of coordination between stakeholders. Our multi-disciplinary perspective, at the interface between socioeconomics and geography, converges towards the ever-renewed quest for adaptability to change in order to survive, a kind of perpetual conquest of innovation and interaction.

In the first section, cheesemakers, indignant about health standards, led us to differentiate between two regimes of market activity with their instruments, their constraints and their own ways of steering action, and ultimately two ways of ensuring sustainability by articulating identity and diversity. It is because they blended the instruments of these two regimes that health standards and pasteurization have become a source of conflicts of coexistence. Yet, however different, such activity regimes are not strictly compartmentalized.

In the second section, the forms of organization of farming and food revolve around the dual dynamic of recognizing the diversity of organizational forms and inventing a common territorial identity. The examples from Auvergne, France; Pisa, Italy; and Parana, Brazil, thus show how actors in the field are finding ways to distinguish themselves by hybridizing modes of production, commercialization and multi-actor interaction. Hybridization makes it possible to sustain farming and food activities, while aligning with the individual and collective strategies of the actors and, in so doing, to contribute to territorial development dynamics.

Hybridization allows for regimes to coexist according to several sustainability dynamics. But it is also a new source of discord. For all those who defend the coherence of their production and marketing regime, hybridization threatens their own identity as an 'artisan' or a reliable 'commercial brand', hence the controversy within the PDOs. They thus constantly seek to better differentiate themselves by advocating the exclusivity of resources, or by highlighting those resources which, like unmixed and non-standardized raw milk, for example, in contrast with pasteurization, hamper the homogenization-based industrial regime.

The different abovementioned regimes and their hybridizations are structured by resources, commercial dynamics, and adjustments of the identity/diversity duo; both aspects are compatible to varying degrees and a possible source of conflict. Their coexistence can also be a resource for the sustainability of territories, provided that there is a commitment to recognizing these different regimes and preserving the resources linked to their own forms of sustainability.

The sustainability of farming, whether in peri-urban or rural areas, requires new types of relationships and territorial anchorage. The quest for better integration into the terrestrial networks of interaction (Latour, 2017) thus constitutes an alternative path for the ecological transition sought. It is an exciting avenue to pursue!

⏩ Acknowledgements

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Chapter 11

Leveraging agroecology to improve milk production and marketing: insights from case studies in Burkina Faso, France and India

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In response to the growing demand for dairy products (mainly in developing and emerging countries) as well as increasingly stringent production and marketing standards (mainly in developed countries), dairy value chain stakeholders have been redesigning their production and marketing models for some years now. The aim is to increase milk production while minimizing unwanted side effects through agroecological practices.

Altieri (1995) and Gliessman (1997) define agroecology as the application of ecology principles to the study, design and management of sustainable agroecosystems. Agroecology has begun to gain ground as the negative impacts of industrial farming (e.g., pollution, soil depletion, loss of biodiversity, contribution to global warming, producers' loss of independence, and health hazards) rise to critical levels. The realm of agroecology has grown tremendously, and is described as standing at the juncture of three interrelated fields (Wezel et al., 2009): 1) agroecology is a science for agricultural ecosystems; 2) agroecology promotes environmentally sound agricultural practices, and 3) agroecology supports a social movement promoting sustainable and equitable food and farming systems. To help operationalize the concept, the FAO has identified ten elements, grouped into three categories, to be considered in the development of agroecological food and farming systems (Wezel et al., 2020):

– Systems that promote: 1) diversity, 2) synergies, 3) efficiency, 4) recycling, 5) resilience;

– Systems that are mindful of: 6) co-creation and sharing of knowledge; 7) human and social values, (8) culture and food traditions;

– An enabling environment for agroecology: 9) responsible governance, 10) circular and solidarity economy.

In this chapter, we offer a renewed approach for agroecological transition based on case studies focusing on low-input or agropastoral milk production systems, predominantly family operated, in Burkina Faso (Haut Bassins, Cascades and Centre provinces), India (Gujarat, Bihar, Andhra Pradesh, Karnataka and West Bengal States) and France (Grands Causses area). We consider agroecology as a way to increase the production of dairy products, rather than a means of de-intensifying farming systems, while also considering the sustainability of natural resources and ecosystems. In other words, agroecology is a form of ecological intensification of dairy production (Wezel et al., 2014).

Following the presentation of our three case studies (Figure 11.4), we will discuss the role of agroecology in each of these situations from the perspective of the FAO framework. We will then conclude with a review of the challenges that remain regarding mitigation of negative environmental impacts and support for inclusive governance mechanisms for production and distribution channels in the face of market deregulation.

⏩ Milk production and marketing: current trends in three contrasting regions

Burkinabe case study

In Burkina Faso, milk is mainly produced by zebu cattle raised on pastoral dairy farms (Pdf) and agro-pastoral dairy farms (APdf), with 5 to 20 dairy cows per farm and a cultivated area between 2 and over 10 ha per farm (Figure 11.1). These farms are mainly lactating breeding systems, where milk is a valuable product to feed the family and generate income. Cows yield little milk (500 to 1,000 L/lactation). They are pasture fed and are given very little fodder or feed concentrates; these are provided mainly at the end of the dry season. Milk production costs amount to less than €0.30/L. A significant share of the milk production is consumed by the family, but the proportion being marketed is rising as demand increases (Vall et al., 2021).

Traditionally, women control the income from the sale of milk on local retail markets, at a price that varies according to the season (€0.60 to €0.90/L). Private mini-dairy processors are now being set up, collecting from 200 to 1,000 L/day. Thanks to a local delivery network (within 50 km of the dairy processors) operated by bicycle or motorbike couriers, the morning milk is delivered to the point of sale by 11 am without requiring any cold chain storage. The purchase price offered by these dairy processors is lower than that obtained from informal operators on the retail markets (€0.50/L); as a result, the share of milk collected by mini-dairy processors remains low (less than 10%). Dairy processors try to secure their suppliers' loyalty by promising them a guaranteed outlet. However, the increase in collection is limited by the lack of written contracts.

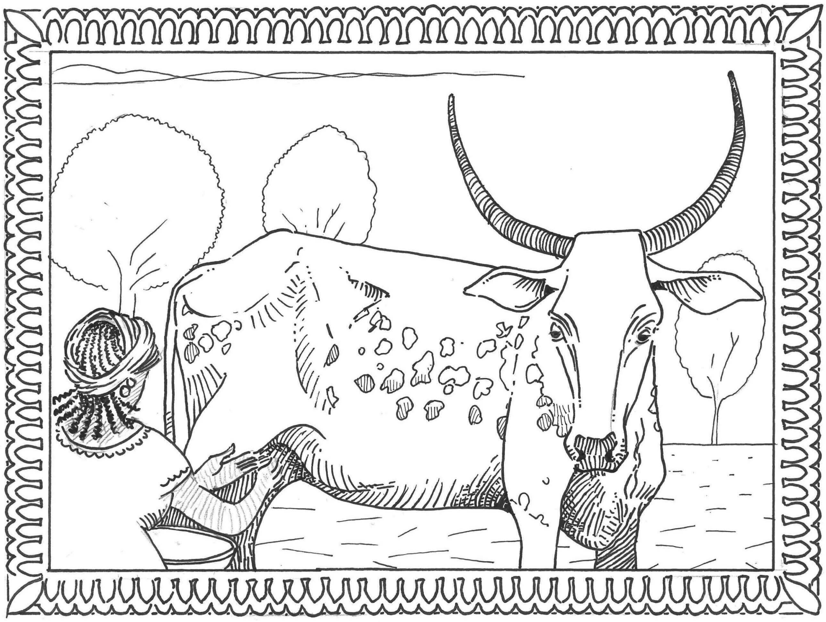

Figure 11.1. Manual milking of a Zebu female in Burkina Faso (Drawing: Éric Vall).

To meet rising demand, some dairy farmers, often from urban areas, have intensified their production at minimal cost within small units of dairy cows (1 to 5 head) or mini-dairy farms (5 to 10 head). This process involves cross-breeding cows housed in stalls (zebus crossed with exotic dairy breeds through artificial insemination). Grazing time is reduced while cows are systematically given crop residues (cereal straw, legume tops) and feed concentrates (cottonseed cake, maize bran). The stall-housing system means that a larger proportion of manure can be recycled as fertilizer. Within the household, the husband often takes over control of the milk (Vidal et al., 2020; Vall et al., 2021).

To expand collection and improve milk quality control, the Burkinabe government is setting up collection centres affiliated with dairy processors. Since dairy processors do not buy milk at prices exceeding €0.50/L, these centres offer producers lower prices to cover their costs (€0.45/L), and so are unattractive. Many dairy processors choose to use imported milk powder, which is cheaper than local milk, widely available, easy to store, and more reliable in terms of quality (Corniaux et al., 2020).

Dairies processing fresh local milk face dual competition from powdered dairy processors (whose products are cheaper thanks to less expensive raw materials) and from the informal sector that absorbs a large share of the local fresh milk (selling it directly at better prices). Dairy processors struggle to provide local milk-based products (milk, yoghurt and curd) at reasonable prices to consumers with low disposable incomes (less than €60 per month per capita) and who consume small amounts of dairy products (under 15 kg per capita per year). All of this occurs in a context where consumers are not aware of whether the dairy product they buy is made with local fresh milk or imported milk powder.

Indian case study

India has the largest bovine population in the world and is the world's largest milk producer (198 million tonnes in 2019). This production is ensured by small herds averaging three heads of cattle or buffalo (Figure 11.2). Animals are used for a variety of tasks, such as draft power, manure production and some meat production (although to a lesser extent due to religious restrictions on slaughter and consumption). Additionally, 70% of these bovines are raised on farms with less than 1 ha of cropland. Feed includes a large proportion of crop residues (wheat and rice straw), which are the main resource to feed bovine animals nationwide (Dorin et al., 2019).

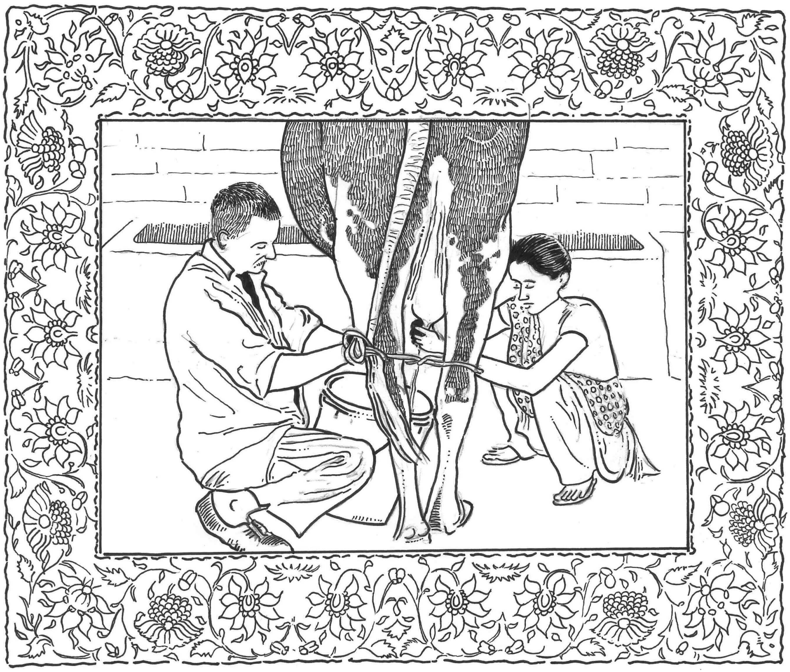

Figure 11.2. Manual milking of a dairy cow in India (Drawing: Éric Vall from a picture of Claire Aubron).

The farms that undertake livestock production are those with the most limited access to land and irrigation water resources (Aubron et al., 2019). Some still rely on the non-food functions of animals (draft power/manure; Cochetel et al., 2019) and others have found milk to be a means of supplementing crop income following improved market access. This quest for milk income has led to changes in farming practices, particularly on small, irrigated farms, in favour of breeds with higher milk yields (Holstein or Jersey crosses with local cows, Murrah buffaloes) and irrigated fodder crops harvested daily on small plots (Napier grass, berseem clover, alfalfa, sorghum, etc.). In some regions, the expansion of milk collection has also led landless agricultural labourers to set up dairy operations. For the past two to three decades dairy farmers have been increasingly using feed concentrates in addition of spontaneous fodder that is collected daily or grazed, whether or not they have land. Usually purchased from cooperatives, these concentrates are sometimes easier to access than fodder and can make up more than half of the dry matter ration.

India has been self-sufficient in milk production since the 1990s. Its per capita average yearly consumption of dairy products has doubled since 1970 to 80 kg, although this figure is still low for a predominantly vegetarian country where milk is the main source of animal protein. This increase is credited to the development of a vast network of dairy cooperatives as part of India's White Revolution (Dorin and Landy, 2009). The National Dairy Development Board (NDDB), established in 1965 as a sui generis organization, supported the development of cooperative industrial value chains. Following the Indian liberal turn of 1991, the NDDB negotiated specific treatment for dairy cooperatives: the Milk and Milk Products Order of 1992 shielded the cooperative industry by imposing area and size limits to private investments. Following the order's repeal in 2002, the NDDB supported the cooperative sector with the promotion of a new 'milk producer company' legal status aimed at overcoming the limitations of the traditional cooperatives (Jenin et al., forthcoming). Nevertheless, since 2002 private processing capacity grew faster than that of cooperatives. Moreover, the industrialization of the dairy sector remains partial in India, with nearly 75% of the production being consumed at home or marketed in informal value chains (fresh milk and artisanal products) (Gupta, 2017).

French case study

Herds of between 200 and 800 Lacaune ewes are bred in the Grands Causses area (Figure 11.3). This breed has been selected for milk production since the 1960s. Breeding is mainly carried out by artificial insemination (a practice prohibited in organic farming, and one which raises agroecological questions due to the use of chemical hormones). Group lambing allows for milk production to run from December to July. Lactating ewes are fed hay, with feed concentrates, at a ratio of 1 kg /L of milk. Ewes graze on temporary grassland in the spring, and occasionally on rangeland in the summer and autumn, when grassland is dry. Temporary grassland is rotated with cereals, which provide straw for bedding and grains for concentrates. Sheep farmers in this region cultivate between 80 and 150 ha per year of grassland and cereals. Manure is used as a supplement to mineral fertilizer.

For several years, seven factories collected and processed milk to produce Protected Designation of Origin (PDO) Roquefort cheese. Prior to 2015, farmgate milk prices were set between processors and farmers. Steps were taken to handle the oversupply issue that emerged in the 1970s, including diversifying cheese types (1980s), introducing quotas (1987) and providing incentives to better distribute production throughout the year (2000s). Farmers were offered a guaranteed and identical base price for milk, regardless of its purpose. These decisions helped promote food self-sufficiency of farms (Aubron et al., 2014), curb the decline in the number of holdings in the area compared to the national average, and slow down the farms' enlargement and intensification process (Quetier, 2005).

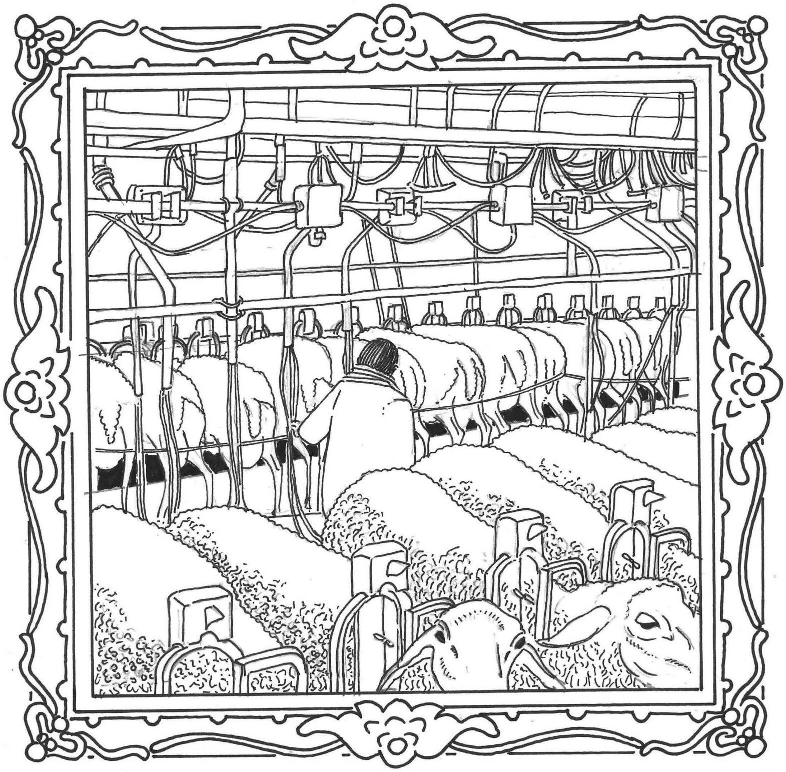

Figure 11.3. Mechanical milking of a herd of Lacaune ewes in the Grand Causses area (Drawing: Éric Vall from a picture of Philippe Hassoun).

Since the 1990s, farmers have been introducing new practices, such as diversifying the flora of cultivated pastures (mixing 10 to 15 species), growing meslin (triticale or barley, peas or vetch) and generally taking a holistic approach to plant and animal health. Others have taken the step of converting to organic farming and no longer use chemical inputs. This conversion was helped not only by the development of organic milk collection rounds, but also by the creation and development of small dairies operating outside the Roquefort inter-branch organization. These small dairies positioned themselves to meet domestic demand for ultra-fresh sheep's milk and organic products.

Farmers involved in these initiatives were and still are encouraged to spread out deliveries. Those who left the Roquefort inter-branch organization have also been able to increase production volumes. From 2015, following the introduction of the European regulation known as the 'Milk Package', the Roquefort inter-branch organization was forced to scrap the quota system and rules governing milk payments. This led to a rise in volumes of milk collected within the inter-branch organization and to further expansion and intensification.

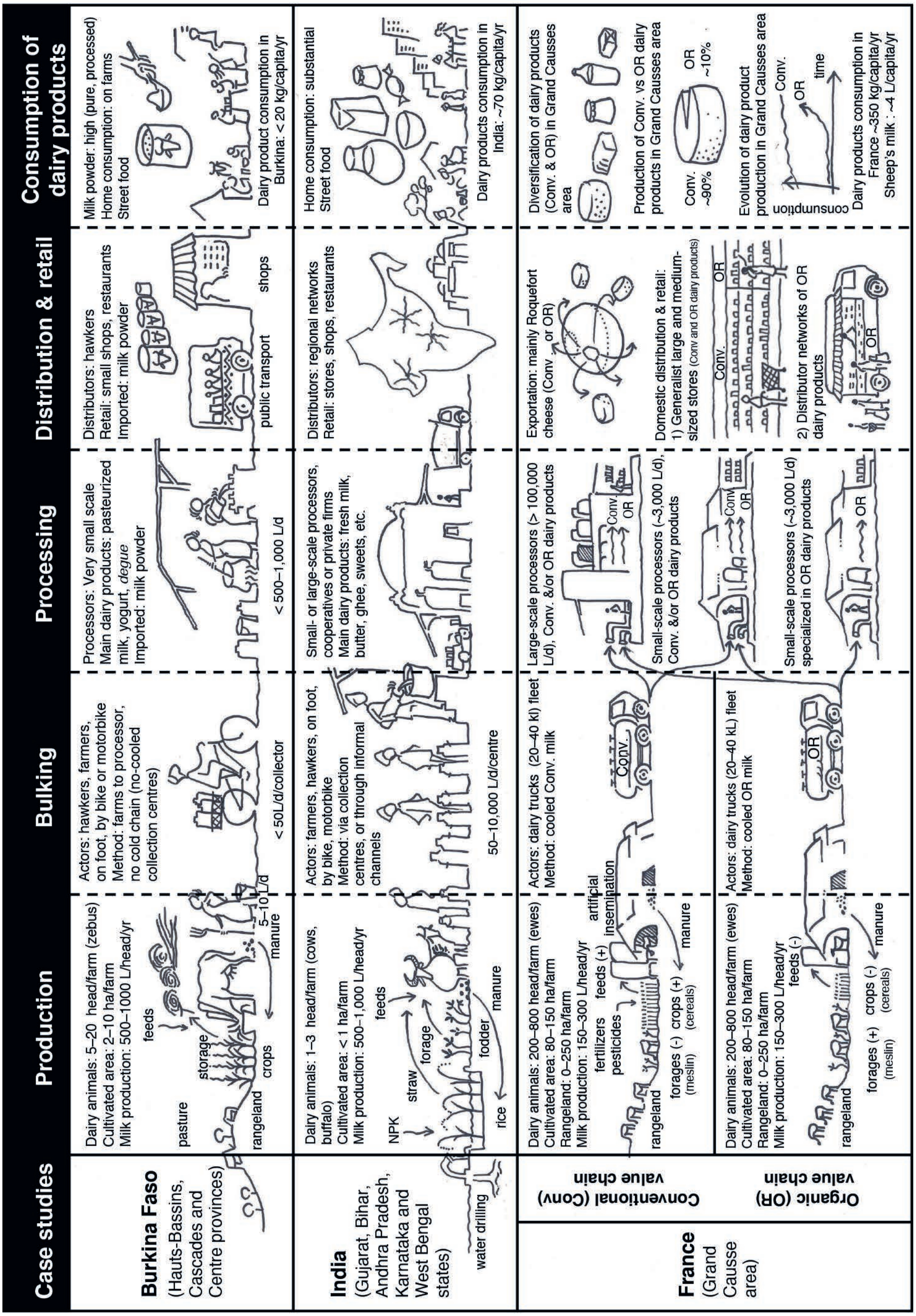

Figure 11.4. Schematic representation of the stages from production at farm level to consumption of milk and dairy products for the three case studies.

⏩ Evidence of agroecology in milk production and marketing systems

Burkinabe case study

Pastoral dairy farms and agro-pastoral dairy farms, mostly Fulani herders, have deeper local knowledge of pastoral resources (vegetation, water) used daily for cattle herding than new dairy farmers from urban areas who have established more intensive mini-dairy farms (Vall and Diallo, 2009). As such, pastoral and agro-pastoral dairy farms exploit the spontaneous pasture-grazing resources to a greater extent than do mini-dairy farms: the daily intakes for pastoral, agro-pastoral and mini-dairy farms are 4 kg, 3.5 kg and 1 kg of dry matter (DM) per cow per day, respectively. However, synergies between agriculture and livestock, as well as recycling of crop and livestock by-products, are more developed among mini-dairy farms and agro-pastoral dairy farms compared to pastoral dairy farms (Vall et al., 2021):
– Stored fodder: 2,300 kg vs 900 kg of DM per cow per year, respectively;
– Recycled manure: 450 kg vs 300 kg of DM per cow per year, respectively;
– Animal faeces lost on pasture: 200 kg vs 400 kg of DM per cow per year, respectively.

The excessive use of feed concentrates by mini-dairy farms reflects an efficiency problem with this resource: for mini-dairy, agro-pastoral and pastoral dairy farms, the figures are 6, 4 and <1 kg of DM per dairy cow per day, respectively. This excessive use also affects the environmental efficiency of these systems, both in terms of fossil fuel consumption and greenhouse gas emissions per litre of milk produced (Somda, 2020). Furthermore, the systematic reliance on artificial insemination and exotic dairy breeds, which helps mini-dairy-farms achieve higher production levels than agro-pastoral and pastoral dairy farms (2,000 vs. 900 vs. 350 L per dairy cow per year, respectively) and meet market expectations, has negative consequences in term of animal welfare: European dairy breeds have a much lower thermal comfort point than the local average temperature. As a result, mini-dairy farms and agro-pastoral dairy farms are more reliant on exogenous inputs, making them less resilient to economic shocks (i.e., sudden rise in input prices) than pastoral dairy farms, which are highly input self-sufficient. High milk prices at farmgate and all along the value chain explain why milk losses and waste are very low (<15%) in this area unlike in developed countries.

With regard to human and social values, women control the milk income on 60% of pastoral dairy systems. This figure drops to 40% on agro-pastoral dairy farms and 18% on mini-dairy farms. Many mini-dairy processors are run by women. Processors have considerable influence over the upstream part of the milk value chain and are a key entry point for tackling such exclusion issues.

Circularity and solidarity values are rarely promoted in current marketing practices. In the face of competition from large-scale milk powder imports, the Economic Community of West African States (ECOWAS), NGOs and farmers' organizations are rallying to promote local production and attempt to introduce more responsible governance practices for the dairy value chain in West Africa (CEDEAO/ECOWAS, 2019 and Corniaux et al., 2020).

Indian case study

In India, synergies between crop and livestock production are strong. Livestock farming has emerged as a powerful means of recycling crop residues, in particular wheat and rice straw, whose production has risen significantly as a result of the Green Revolution. On some farms and in certain regions, livestock farming still provides draft power and contributes to the management of cropland fertility (both through nutrients and organic matter that improve soil structure), while minimizing the use of chemical inputs and irrigation water. However, the type of agriculture with which it is associated consumes, when irrigated, a great deal of chemical fertilizers (particularly nitrogen) and fossil fuels (not least for pumping water). Overall environmental efficiency remains low, due in part to high consumption of fossil fuels, and even if livestock is mainly fed by crop residues (Vigne et al., 2021; Aubron et al., 2021). In addition, the fact that herds raised on irrigated farms are dedicated to dairy farming generally leads to a decline in the importance of other livestock functions (e.g., tractors being used instead of draft animal power), reduced breed diversity (in favour of more productive breeds, achieved by means of artificial insemination) and increased purchases of concentrates that reduce farms' self-sufficiency.

The extensive cooperative milk collection, processing and distribution network established during the White Revolution is a model of inclusiveness that has won much international praise (World Bank, 2012). This success is based both on an innovative cooperative model and on a sector-specific public policy that supports its development. The strength of the cooperative network stems from a combination of dairy producers' substantial involvement in the collection process and the search for economic efficiency at the processing and marketing stages, in particular through economies of scale and inter-site coordination. The role played by the NDDB in building and subsequently steering this cooperative network appears to be central and suggests that public bodies are able to foster the development of common industry resources and shape inclusion (Dervillé et al., forthcoming a), which is not the case in many developing countries in West Africa. However, the actual involvement of farmers in decision-making processes at all levels of the network remains limited. Furthermore, although farmers with little land and irrigation water are definitely included in this dairy market, the income generated remains very low in relation to that derived from irrigated crops: the whole system is a long way from being able to lift people out of poverty and ensure greater equity among rural families in the areas studied (Aubron et al., 2019). In addition, the spatial distribution of the dairy cooperatives is very uneven, leading to very different conditions among dairy farmers in terms of access to dairy markets and income (Dervillé et al., forthcoming b). Moreover, the dairy cooperatives played a key role in structuring industrial dairy chains, and agroecology has not been a priority so far. Initial shifts towards agroecological practices entail the development of conservation programs for local livestock breeds as well as the recent launch of a ration-balancing programme aiming at improving the efficiency of feeding practices.

French case study

Technical changes seen in the Grand Causses farms that adopted agroecological practices are based on crop diversification. The introduction of legumes helps to reduce, if not eliminate, the use of mineral fertilizers. This introduction complements the recycling process already implemented between crops and livestock through manure. Farmers diversify their crop production to boost farm resilience against increasingly frequent droughts (because crops grown on the same farm do not all have the same sensitivity to drought). Crop diversification also helps to improve the protein autonomy of herds and therefore the overall efficiency of the livestock systems. Conversion to organic farming by some farmers is largely based on this diversification approach, in addition to other zootechnical or agronomic practices, such as false seeding for weed control (Vidal et al., 2020).

However, these holdings, even under organic farming, are still highly fossil fuel intensive (motorized fodder production and harvesting, milking equipment). Additionally, volume increases and production time lags lead to reduced use of rangelands. In order to feed lactating ewes, particularly in summer, farmers favour cultivated resources over rangelands (Aubron et al., 2014). This contributes to the closing over of these rangelands, threatening the biodiversity of open habitats, despite their importance being recognized by the EU with their designation as Natura 2000 areas, as well as by UNESCO (Vidal, 2019).

As the oldest French cheese to be awarded PDO status (1925), Roquefort remains a symbol of food culture and tradition, even though its consumption is steadily declining. Alongside it, the range of products made from sheep's milk has expanded greatly, with the production of other types of cheese, partly derived from local cheese-making traditions and increasingly produced under organic farming standards, as well as ultra-fresh dairy products. These products meet the needs of consumers concerned with healthy eating (alternatives to cow's milk proteins for people who are allergic, products free of chemical residues) and environmental issues (pollution from chemical inputs, biodiversity conservation).

The emergence of other dairy processors operating outside the Roquefort inter-branch organization and the introduction of the EU Milk Package in 2015 destabilized governance and put an end to the price guarantee for producers. However, recent dairy industry restructuring should help strengthen producers' bargaining power, which is often undermined in highly competitive and deregulated environments. The impact of these changes in the sector for the agroecological transition of farms remains in question. Finally, the development of production under organic specifications, supported by dairies both inside and outside the Roquefort system, contributes to the establishment of some agroecological practices, although the role of spontaneous vegetation in animal food systems is often weakened.

⏩ Discussion and conclusion

The one aspect common to all three case studies is an increase in milk production, either at farm or collection pool level, for a variety of reasons: 1) a rise in the overall demand for milk, due to population growth and greater individual consumption (Indian and Burkinabe case studies); 2) a willingness on the part of some dairy farmers and processors to promote local milk production in the face of competition from imported milk powder (Burkinabe case study); 3) a growing consumer appeal for organic, ultra-fresh dairy products and sheep's milk dairy products (French case study); and 4) efforts to achieve higher delivery volumes at farm level to ensure income. Analysis of the above case studies shows that while agroecological practices have indeed been introduced as part of this process of increasing production and marketing, a number of challenges remain, particularly from an environmental and social point of view.

Crop-livestock integration is often central in dairy farms (Figure 11.4), and this was true in the three case studies. Crops provide feed for livestock via straw (Indian and Burkinabe case studies), fodder crops (Indian and French case studies) and cereal crops (French case study). Livestock contributes to land fertility through plant biomass recycling and manure production, involving in some cases animal movements between rangeland and cultivated areas (Burkinabe, French, and occasionally Indian case studies). Crop-livestock integration can also provide energy for transport and farming (Indian case study, and sometimes Burkinabe case study). In the Indian and Burkinabe case studies, dairy farming is often associated with intensive cropping systems (cotton, irrigated rice) on the same farm. Dairy cows benefit from the by-products of these crops (stems, hulls, straw), such as fodder and bedding – by-products that are available in large quantities because of the inputs applied to these crops (mineral fertilizers, pesticides, irrigation). The cows recycle this raw material into organic manure, which is returned to the fields and thus improves soil fertility. Crop-livestock integration promotes several elements of agroecology (diversity, synergies, efficiency and recycling), therefore contributing to overall system resilience. However, these farms can also be highly fossil-fuel intensive (motorized equipment in the French case study, water pumping and use of synthetic fertilizer in the Indian case study) as well as heavy users of agrochemicals (the pesticides used on crops like cotton and cowpea not only negatively impact insect populations such as bees, but also the quality of cowpea tops fed to livestock in the Burkinabe case study).

The primary technical means for increasing production is genetics (both animal and plant), with the selection of pure Lacaune breeds (French case study) or the use of exotic dairy breeds crossed with local cattle through artificial insemination (Indian case study, and increasingly in the Burkinabe case study). These crossbred animals may be less suited to their local environment and thus require more veterinary care (e.g., to prevent trypanosomiasis in the Burkinabe case study). The second technical means, which helps optimize the first one, is increased use of feed concentrates (Indian and Burkinabe case studies). Their production requires chemical inputs and energy, and when purchased, they must be transported. These processes contribute to the negative environmental impacts of livestock farming (GHG emissions, pollution). In some mini-dairy farms (Burkinabe case study), their excessive use can also be a problem for dairy cow health (risk of acidosis). The transition to organic farming (French case study) has generally led to a further increase in milk production per ewe, as well as a shift in the production period as requested by dairies. However, for many farmers, this change has resulted in a decrease in the use of rangeland spontaneous vegetation, with a reduction in the maintenance of open environments.

From a social point of view, greater milk production and marketing does not automatically lead to social inclusion and equity. Farms with fewer resources for dairy intensification (land and irrigation water in the Indian case study, arable land in the French case study) produce less than the larger farms with which they compete. As a result, their numbers continue to fall rapidly (French case study) and their income from milk is very low compared with that from irrigated crops (Indian case study). Due to their isolation, some farmers are also excluded from dairies' collection routes (pastoralists and agro-pastoralists during certain seasons in the Burkinabe case study, and farmers in certain parts of the Causses region in France). Finally, in the Burkinabe case study, women tend to lose control over milk income as volumes and dairy sales increase (milk marketing brings into question the balance between multiple milk uses at farm level: household self-consumption vs women's income vs calf feeding). The results gathered from this study suggest that inclusion can be promoted in a number of ways, such as establishing a vast cooperative network for the collection, processing and distribution of milk under the supervision of a public body (Indian case study), introducing inter-branch collective action and standards to manage competition between farmers and between dairies (French case study), or promoting corporate social responsibility actions among dairies (Burkinabe case study). The first two approaches seem to have been undermined by economic deregulation and are in the process of being redefined (producer companies in the Indian case study, producer organizations in French case study).

In these contrasting situations, it seems that, in order to combine the increase in milk production with a virtuous process of agroecological transition, trade-offs must be made and a holistic approach is required at the value chain level, with efforts being spread across all its segments.

⏩ Acknowledgements

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Section VI

Local ressources management as a driver of food security

Chapter 12

Food security and natural resources: diversification strategies

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This chapter deals with two major issues rural households face in tropical areas: preserving natural resources and guaranteeing food security. Tackling these two challenges simultaneously may require developing profitable production systems that can both guarantee food security for farmers, while also ensuring sustainable management of natural resources. Doing so will require questioning the direct and indirect links between household food security and biodiversity at the farm and landscape levels. To what extent does the diversification of production systems influence household food security? And conversely, to what extent does the level of food security influence production system performances? Is it possible to reconcile environmental performance and food security, and could diversification be a viable solution? Are there mechanisms capable of supporting this dual objective? This chapter aims to answer these questions through five case studies centred on diversification strategies, including diversification of species in cultivated landscapes and diversification of agricultural activities: 1) agroforestry parklands in Senegal; 2) cocoa-based agroforestry systems in the Peruvian Amazon; 3) cereal-cowpea intercropping systems in Zimbabwe and sub-Saharan Africa; 4) perennial palm oil monoculture grown on land converted from diverse forest cover or previously cultivated land in Indonesia; and 5) extensive cattle production systems rapidly extending into the heart of the Brazilian Amazon rainforest. The findings presented here suggest technical solutions likely to resolve the trade-off between profitability and sustainability, while underlining the socio-economic obstacles to their implementation.

⏩ Diversifying farming systems to improve food security in Sahelian agroforestry parklands

A diversity of tree species and tree uses

In a context of increasing environmental and climatic concerns, agroforestry, defined as the integration and management of trees and woody shrubs with crops and livestock, has been acknowledged as an important contributor to food security and sustainable use of land and biodiversity in sub-Saharan Africa (Rosenstock et al., 2019). Agroforestry parklands are a specific case of agroforestry systems illustrative of Sahelian agricultural landscapes, where trees have been preserved or introduced for centuries by farmers in order to benefit from the numerous socio-ecosystem services they provide (Sinare and Gordon, 2015). In 2018, in the Niakhar and Nioro districts of Senegal's groundnut basin, we surveyed 412 households and conducted tree inventories for two types of dominant parklands in the region. We identified more than 60 different tree species, covering a large range of tree uses (Figure 12.1). The reported uses could either be categorised as providing ecosystem services (e.g., firewood, fodder, food) or regulating ecosystem services (soil fertility and shade). Households identified food provision (either direct or indirect, i.e., through greater crop yield) as the main use for the different tree species. The legume tree *Faidherbia albida* was the species with the most diversified uses, including soil fertility improvement and hence crop yield, leaves used as fodder for livestock, and firewood.

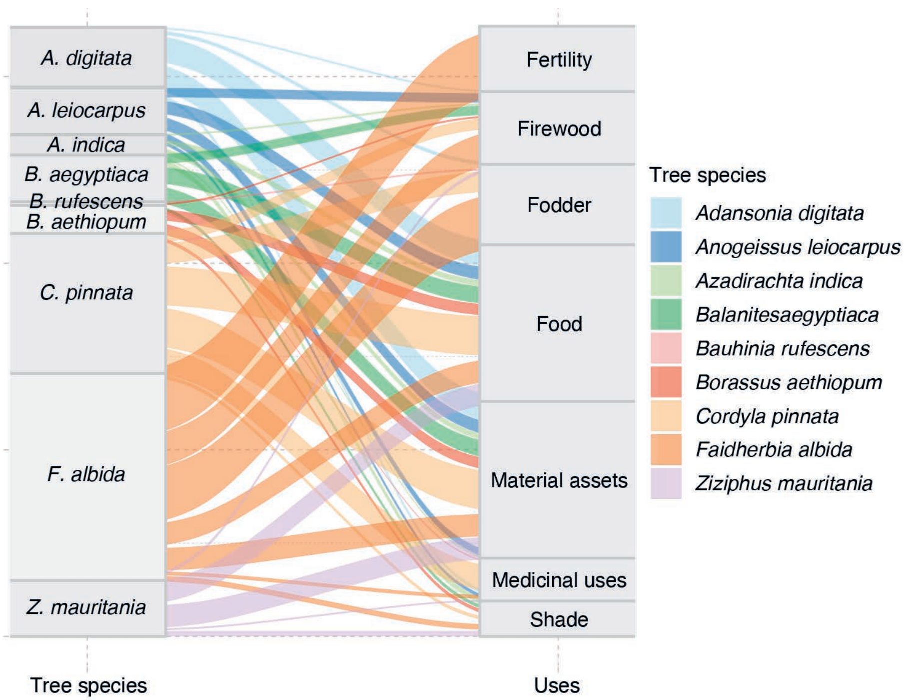

Figure 12.1. Sankey diagram linking the most important tree species (i.e., representing more than 3% of total trees) and the different tree uses (Source: Leroux et al., 2021).

The width of links is proportional to the number of times a tree species was cited for a specific use. Only the most represented tree species of both parklands are displayed (i.e., representing more than 3%).

Contribution of tree diversity to food availability

Different combinations of tree species and/or densities can lead to contrasting effects on crop productivity and hence food availability. Studies analysing tree diversity contribution to food availability are scarce and often consider only one species at a time. We monitored 70 farmers' fields for yield, crop management, soil type and soil nutrients during the 2018 cropping season. We constructed landscape diversity indicators using geospatial data. Millet was the main staple crop of the study area; as such, millet yield was used as a proxy for household food availability. Using machine learning (i.e., a gradient boosting machine), we investigated the contribution of landscape diversity, soil type and nutrients, and crop management in explaining millet variability in the two contrasted parklands. Among the highest contributing factors to millet yield variability, landscape diversity (i.e., tree species richness and tree density in field surroundings) accounted for 53% and 47% of the relative importance in Niakhar and Nioro, respectively. We also showed that a greater diversity in the parkland structure had a positive impact on millet yields, but only up to a certain level of diversity, above which no improvement in millet yields was observed. The way the different components of the parklands are mixed and managed strongly influence other ecosystem services (e.g., water regulation, pest incidence), with trade-offs and/or synergies occurring. Beyond the positive influence on millet yield at plot scale, correlation analyses showed that tree species diversity (assessed at household level, i.e., considering all of a household's fields) was significantly associated with greater millet production per capita ($r=0.38$). This suggests that optimising the management of tree density and species diversity may achieve greater household food availability and higher agricultural income.

Contribution of tree to food security and coping strategy

Using the Household Food Insecurity Access Scale (HFIAS) as an indicator, we analysed the outcomes of household socio-demographic surveys to investigate which factors were associated with food security, controlling for several socio-demographic variables. Half of the surveyed households experienced moderate or severe food insecurity. Econometric models for censored data, used to account for zero values of the dependent variable (e.g., tobit), showed that food security is positively associated with male-headed and wealthier households (more house assets and cows) and larger income from remittances (significant at 5%). Food security is also positively and strongly associated with higher food production, including millet production (significant at 1%). This tends to confirm the indirect contribution of landscape diversity to food security through improved food availability. Finally, food insecure households rely more on trees beyond their own plots, in community space or neighbours' plots, year round (significant at 1%). While diversifying access to trees does not allow most vulnerable households to be food secure, it might reduce the worst forms of food insecurity. In addition, for food insecure households, collecting from trees as a coping strategy during lean months was mentioned more often (significant at 1%). This coping strategy is used in the most severe situations, alongside selling productive or other assets and forced migration. These findings suggest that preserving parkland trees at both the farm and community scales, and allowing more vulnerable households to have access to them, would provide a safety net and increase these households' ability to cope with chronic and seasonal food insecurity.

⏩ Cocoa-based agroforestry in the Peruvian Amazon: does higher cultivated diversity provide better food security?

Agroforestry practices and plant diversity among indigenous cocoa producers

High levels of poverty, food insecurity, child mortality and morbidity persist amongst indigenous peoples in the Peruvian Amazon (Brierley et al., 2014). More than half of children under five in this region suffer from chronic undernutrition and anaemia, far above the national averages of 13% and 34%, respectively (Diaz et al., 2015). The health systems of diverse indigenous populations of the Peruvian Amazon are based on an integrated understanding of the world, where high native plant and animal biodiversity provides resources for nutrition and health and holds significant cultural value (Jones et al., 2018). Agroforestry practices relying on the association of crops or animals with trees to enhance ecosystem services are traditionally used by indigenous populations and support high levels of biodiversity.

We studied the Awajún indigenous communities living in the Amazonas department of northern Peru, where cocoa-based agroforestry systems (CAFS) are a source of both income and food. We found that these systems host more than 74 plant species intercropped with the cocoa trees. We hypothesised that a higher cultivated diversity in the CAFS is correlated with improved household food security and lower prevalence of malnutrition. We tested this hypothesis in two different Awajún communities located along the Marañon River, one a remote community accessible only by boat (Chipe), and the other accessible by road and river and connected to outside markets (Urakusa). We found a higher total diversity of plants cultivated in Urakusa's CAFS, with a higher number of forest-related species (Table 12.1). However, the cocoa tree population in Chipe (a mix of low-yielding native cultivars) is significantly more genetically diverse than in Urakusa (few high-yielding introduced varieties planted in larger plots). Finally, CAFS in Chipe host more Musaceae, forest and timber tree species but fewer roots, tubers, fruit and palm trees, which are all found in nearby forests, and fewer annual crops, which are cultivated on the river banks during the dry season.

Food security and malnutrition in cocoa producers' families

Households in the Urakusa community display a slightly higher dietary diversity than those in the Chipe community (Table 12.1). Higher dietary diversity in Urakusa could be explained by higher plant diversity, but it is more likely the result of greater access to imported products due to road proximity. In this community, households consume a lower share of self-produced food (Table 12.1), indicating greater dependence on local markets supplied with imported food. Such dependence on imported products might explain the higher sense of household food insecurity measured by the HFIAS in the Urakusa community, compared with those in the Chipe community, which are used to relying on forest resources available year-round. Because imported products are potentially energy-dense and nutrient-poor, and include more processed and ultra-processed food, the dependence on imported products might explain overweight being more than twice as prevalent in women in the Urakusa community as in the Chipe community. While dietary diversity and food security differ between the two communities, both communities display a similar prevalence of stunting among children.

Table 12.1. Characteristics of the Urakusa and Chipe indigenous communities in the Peruvian Amazon. Source: Da Silva et al., 2018.

Community	**Urakusa**		**Chipe**	
Peruvian province	Bagua		Condorcanqui	
Connection with markets	Easy, by road and boat		Remote, by boat only	
Population	700 inhabitants		1,000 inhabitants	
Cocoa-based agroforestry systems (CAFS)				
Plot size	Medium-Large		Small	
Cocoa varieties	1–2 introduced varieties		Mix of native cultivars	
Cocoa yield	High		Low	
Cocoa tree density	Medium		High	
Associated plant diversity (species richness) at community level	59		42	
Forest-related species	40%		10%	
Timber and forest trees	11%		21%	
Musaceae (plantain and banana)	13%		29%	
Palm and fruit trees	41%		30%	
Root and tubers	14%		4%	
Annual crops	1.5%		0.5%	
Food security indicators	*May***	*November***	*May***	*November***
Household Food Diversity Index (HFDI*)	50%	18%	60%	17%
Prevalence of stunting*	37%	45%	38%	41%
Prevalence of overweight*	50%	53%	18%	28%
Prevalence of traditional dietary pattern*	36%	31%	52%	39%
Prevalence of food insecurity*	55%	61%	30%	18%

***HFDI**: this index was calculated based on 10 food groups with a high potential to contribute to the micronutrient adequacy of diets (the same as those used for the MDD-W) and that are consumed by a household in a week. The figures show the percentage of households that do not eat at least five of the ten possible food groups.

Stunting: Height-for-age for children younger than five, compared to a reference (z-score).

Overweight: BMI≥25 kg/m^2 for women.

Traditional dietary pattern: A household was defined as following a traditional dietary pattern when more than half of the food consumed within the household is self-produced.

Prevalence of food insecurity: Based on the Household Food Insecurity Access Scale (HFIAS), which is an experience-based measure of household food security over a one-month period.

****May** is the end of the rainy season and **November** is the end of the dry season.

Cropping diversification strategies and their effects on food security and malnutrition

We also provided evidence on the role played by CAFS in alleviating 1) the lack of traditional forest resources for indigenous communities living far from the forest, and 2) the lack of income and poor access to markets and processed products for remote communities living near the forest. Communities such as the Urakuza use their CAFS to continue cultivating traditionally domesticated plant species, particularly medicinal rather than edible plants, among introduced cocoa varieties. These strategies result in a substantially larger share of imported food in their diet. Unsteady sources of income for purchasing foods are supported by 1) access to off-farm jobs, and 2) more intensive management of the cocoa tree population inside the CAFS, brought about by development projects and built on a highly productive, foreign and homogenous genetic base. These strategies perpetuate vulnerability to food insecurity and child undernutrition, in addition to increasing the risk of overnutrition by relying on imports of processed and ultra-processed products.

Meanwhile, communities such as Chipe use their CAFS for producing cash crops such as cocoa, wood and plantain, and rely mostly on the forest for food and medicinal plants. Because they cannot afford to transport bulky harvests, they cultivate small plots where native cocoa trees are more densely planted in order to offset the low yield per tree due to the varieties with a better yield per hectare. While these communities are significantly less vulnerable to changes in external markets and income sources, they still face undernutrition issues characterised by low dietary diversity and child stunting. Our findings thus suggest that CAFS may very well be associated with various forms of malnutrition and food insecurity.

⏩ Cereal-cowpea intercropping in sub-Saharan Africa: implications for soil fertility and food security

Intercropping with legume crops to restore soil fertility

Contrary to popular belief, crop yields in many countries of sub-Saharan Africa (SSA) are more nutrient-limited than water-limited. Poor soil fertility and nutrient availability are the major biophysical limitations to crop production in SSA (Sánchez, 2002). Sandy acidic soils are widespread and regularly 'non-responsive' to mineral fertiliser application, meaning that crop yield increases are very limited following the addition of recommended amounts of mineral fertiliser. For these soils, it is highly recommended to simultaneously add organic amendments together with mineral fertiliser to increase fertiliser efficiency. However, the availability of biomass or organic amendments to improve soil fertility in SSA is often limited due to competition for other uses, such as livestock feed. Continuous nutrient mining without replenishment exacerbates the poor fertility of these soils. In such a context, using nitrogen-fixing plants in cropping systems can help restore soil fertility (Giller and Cadisch, 1995), while also offering opportunities for crop diversification.

Cowpea (*Vigna unguiculata* L. Walp) is one of the major grain legumes cultivated by smallholder farmers in SSA, either in rotation with staple crops or as an intercrop (Figure 12.2). It is a drought-tolerant crop, which performs better than other legumes under erratic rainfall. In sub-humid regions, cowpea is often intercropped with maize (*Zea mays* L.), whilst in semi-arid regions, it is intercropped with sorghum (*Sorghum bicolor* L. Moench) or pearl millet (*Pennisetum glaucum* L.R.Br). We systematically reviewed cereal-cowpea intercropping systems in SSA, and estimated that cowpea fixes 36 kg N ha^{-1} on average when intercropped with cereals (Namatsheve et al., 2020). The average annual nitrogen imbalance (or depletion) rate for cropland in SSA is estimated at 22 to 30 kg N ha^{-1} (Giller and Cadisch, 1995; Sánchez, 2002). If cowpea residue is left in the field, this could help counteract this imbalance. Nitrogen fixation could thus be boosted by selecting the right legume varieties, inoculating *Rhizobia* strains, liming, and adding phosphorus.

Intercropping with legume crops to increase land productivity

We found higher land productivity when cowpea was intercropped with maize, sorghum and pearl millet compared with sole crops, with average land equivalent ratios of 1.42, 1.26 and 1.30, respectively (Namatsheve et al., 2020). Yields of cereal crops are slightly but significantly reduced, but the total production of grain per hectare is higher when cereals and cowpea are intercropped rather than grown as sole crops. Maize is the main staple crop in several SSA countries, especially in eastern and southern Africa. Farmers therefore tend to favour maize production over other crops. As a result, many fields are under maize monoculture, with negative consequences in terms of soil nutrient depletion and pest management. Consequently, access to market and profitable prices for the legume crops are crucial to compensate for the lower maize yields and encourage a broader adoption of such cereal-legume intercropping systems.

Diversifying production with more nutritious crops

We carried out an on-farm field experiment of maize-cowpea intercropping systems (Figure 12.2) over two cropping seasons in Zimbabwe. We found no difference in maize and cowpea grain mineral contents in intercropping systems compared with sole crops (Namatsheve et al., 2021), contrary to several studies that showed that intercropping could improve iron and zinc nutrition of plants through rhizospheric processes (Zuo and Zhang, 2009). We therefore concluded that intercropping was either not an agronomic biofortification option in these nutrient-depleted soils, or that the design should be modified (cowpea planted in maize rows instead of between rows to maximise interactions). However, grain mineral contents (Fe, Zn, Mn, Cu, Ca, Mg, P, K) were, as generally observed, much higher in cowpea grains than in maize grains, for all nutrients considered. This has major implications, as iron and zinc deficiencies in humans are highly prevalent worldwide, and especially in Zimbabwe, with detrimental health consequences. For instance, in Zimbabwe, 27% of children under five suffer from stunting due to macro- and micronutrient deficiencies, and 29% of women of childbearing age are anaemic (UNICEF, 2019).

A shift in diet from maize-based meals to a more diversified diet including more pulses could thus contribute to solving this problem. In addition, cereal-legume systems could definitely play a role in supporting a shift towards more diversified diets (Bezner Kerr et al., 2019). However, the mineral content of grains can largely vary from one season to another since plant nutrition is affected by soil water availability and is therefore impacted by dry spells and erratic rainfall.

Figure 12.2. Maize-cowpea intercropping system in Zimbabwe. ©Rémi Cardinael.

⏩ Palm oil expansion and food security in Indonesia: heterogeneity and inequality effects

Food security could be achieved by diversifying income sources

Food security is not just about production; it also encompasses food availability at affordable prices and ensuring environmental sustainability. Accordingly, food security is related to diversification and market access, both in terms of income sources and crop choices. In developing countries where families include many adult members who earn their livelihoods through different activities, the income needed to purchase food can be procured in other ways than by producing staple crops, such as via cash crops, out-of-farm labour and remittances sent by migrants. Crop diversification might occur at the expense of the benefits associated with specialisation, such as economies of scale and high productivity in the 'best' activity. However, specialisation in one profitable crop often entails upfront payment for land preparation, seeds and inputs, which not all producers can afford. Specialisation also increases the dependence on one crop, which may fail or whose price might fluctuate widely. Lastly, specialisation in one crop through intensification can also have an environmental cost as the soil nutrients have no time to regenerate.

Oil palm expansion in Indonesia is an enlightening example of how market access matters for food security. Oil palm is a perennial crop that is used as a cooking oil, industrial input and biofuel. The crop is cultivated over 25 to 30 years, with an initial three-year period before the trees start producing. Good seedlings and annual fertiliser use can boost productivity. According to FAOSTAT data[21], nowhere has this crop's expansion been more striking than in Indonesia, where the cultivated land area has increased from 0.5 m hectares in 1980 to 12 m ha in 2017. Indonesia is now the world's top producer of palm oil, accounting for half of global production. This huge expansion has been identified by the Indonesian government as a major contributor to poverty reduction (Rival and Levang, 2013). However, part of the expansion of palm plantations has come at the expense of forests,[22] leading to losses in biodiversity and soil quality (Dislich et al., 2017) and the use of chemical inputs in intensified cropping systems has led to various environmental impacts (Bessou and Pardon, 2017). Looking at the impact of the expansion of palm oil plantations on rural households in Indonesia, we focused on two issues that are related to food security and crop diversification: general equilibrium effects that link the products and the factor markets, through changes on local prices and wages, and distributional effects between rich and poor.

Looking at all households living in a given community, and not only food crop producers

Households working in the palm oil sector were not the only ones who benefitted from oil palm expansion. Through general equilibrium effects on local wages and prices, the expansion of oil palm has also affected other households in the area. Industrial plantations require infrastructures, such as roads, which improve market access for other produce as well. Thus, we compared all households in areas where palm oil plantations were introduced between 1995 and 2005 with similar areas that were suitable for palm oil production but still without plantations in 2005. The extended time span made it possible to compare the same districts over time and control for unobservable differences between districts (such as political or historical backgrounds) potentially associated with entry into the palm oil sector.

21. FAOSTAT database can be reached here: https://www.fao.org/faostat/
22. Between 1990 and 2008, 17% of deforestation was directly linked to palm plantations in Indonesia (Cuypers et al., 2013).

Distributional effects matter for food security

While the general public often associates palm oil with industrial plantations, in fact, smallholders hold a significant share of total plantations (about 40 percent of total area in 2015). Moreover, because many industrial concessions are now certified by the Roundtable on Sustainable Palm Oil (RSPO), most of the land acquired through expansion in recent years is now in the hands of smallholders. Yet, palm oil smallholders are hard to identify because of their diversity. Historically, oil palm development in Indonesia has been based on joint ventures between plantation firms and local communities. Villagers allocate land to a firm (forming so-called *nucleus plantations*); in exchange, the firm creates family plantations (the *plasma*), which depend on the main firm for credit, seedlings, inputs and technical assistance, and which then deliver their produce to the firm's mill (since it must be processed within two days after harvest). In addition, other smallholders are *independent*: they are newcomers, or former *plasma* households who have repaid their debt to the firm and may or may not be still dependent, to a varying degree, on the firm's mill for processing. Smallholders' plantations are thus very heterogeneous in terms of status, size, and economic and environmental efficiency.

Oil palm expansion led by these heterogeneous independent smallholders is likely to increase inequality. With constraints on access to technical knowledge, capital and secure land titles, not all independent smallholders can afford economically and environmentally efficient good practices nor smooth out the risk of international price fluctuations. We matched maps of industrial plantations (Austin et al., 2017) in various years with nationwide household budget surveys which reported the location of each household. We compared food consumption in villages where oil palm plantations were created within a 10-km radius between 1996 and 2005 with villages not affected by oil palm expansion. We assessed the impact of proximity to oil palm plantations on local distribution of consumption. We looked at the share of household consumption that was purchased as an indicator of market access. We found that households relied more on markets for their food when they lived in a plantation area, and that this change benefitted the poor households in these areas more than the rich households.

⏩ Switching to more diversified and sustainable production systems in Brazil: effectiveness and permanence of REDD+ programmes

REDD+ initiatives to reduce deforestation in the Amazon

Certain cropping systems such as soya bean production or extensive livestock farming, as practised in the Brazilian Amazon, have negative consequences for the environment, including increased fertiliser and pesticide runoff, overuse of freshwater resources, greenhouse gas emissions, and biodiversity loss, that are too substantial for these systems to be maintained. As a result, there has been a proliferation of subnational initiatives financed by the United Nation's REDD+

programme (Reducing Emissions from Deforestation and Forest Degradation) for many years in the Brazilian Amazon (Sills et al., 2014). Most of these REDD+ initiatives are hybrids of the integrated conservation and development project (ICDP) approach and new forest conservation approaches, such as payments for environmental services. They take the form of conservation programmes in which participants are encouraged to eliminate their reliance on deforestation activities altogether by switching towards more diversified and sustainable agricultural production systems (more intensive farming and greater crop diversity typically). These programmes aim to resolve the trade-off between preserving forest resources and guaranteeing food security for small landowners (Duchelle et al., 2017).

The Sustainable Settlements in the Amazon project, a Brazilian REDD+ flagship project that aimed to curb deforestation, offered technical assistance and conditional payments[23] to 350 households for maintaining forest cover on at least half of their land between 2013 and 2017. The participants in the project lived in 13 settlements located in the municipalities of Anapu, Pacajá, and Senador José Porfírio, near the BR-230 Trans-Amazonian Highway, an area with high past and present levels of deforestation. The project sought to provide technical assistance to these smallholders, help them comply with the law, and engage in a no-fire agricultural transition. These actions were aimed at facilitating a transition towards more diversified and sustainable agricultural practices and helping smallholders to intensify livestock farming and diversify crop production. Simonet et al. (2019) define the Sustainable Settlements project as a multi-component REDD+ project mixing incentives, disincentives and enabling measures.[24] We assessed the applicability of publicly available remote-sensing datasets to evaluate the impact of the Sustainable Settlements programme in the Brazilian Amazon (Demarchi et al., 2020).

Effectiveness of REDD+ programmes

First, we reconstructed forest loss for the period between 2008 and 2018 of 21,492 farms in the Trans-Amazonian region, using data derived from two land-cover change datasets: Global Forest Change (GFC) and Amazon Deforestation Monitoring Project (PRODES). Second, we evaluated the consistency between the two data sources. Lastly, we estimated the long-term impact of the Sustainable Settlements programme using microeconometric techniques that draw from pre-treatment outcomes of non-participants to construct counterfactual patterns of participants in the programme. Although the deforestation estimates at the farm level vary considerably from one dataset to another, we found that an average of about 2 hectares of forest were saved on each of the 348 participating farms during the first years of the programme, regardless the data source used (Figure 12.3).

23. Conditional payments or payments for environmental services are financial incentives offered to farmers or landowners in exchange for managing their land to provide some sort of ecological service.

24. Despite the proliferation of REDD+ initiatives in recent years, their effectiveness has rarely been rigorously evaluated (Jayachandran et al., 2017; Simonet et al., 2019; Roopsind et al., 2019). This is partly due to the low availability of data required for this type of analysis. Over the past 20 years, however, availability of remote-sensing data for detecting changes in land cover worldwide has evolved dramatically, offering new opportunities for the evaluation of forest conservation programmes.

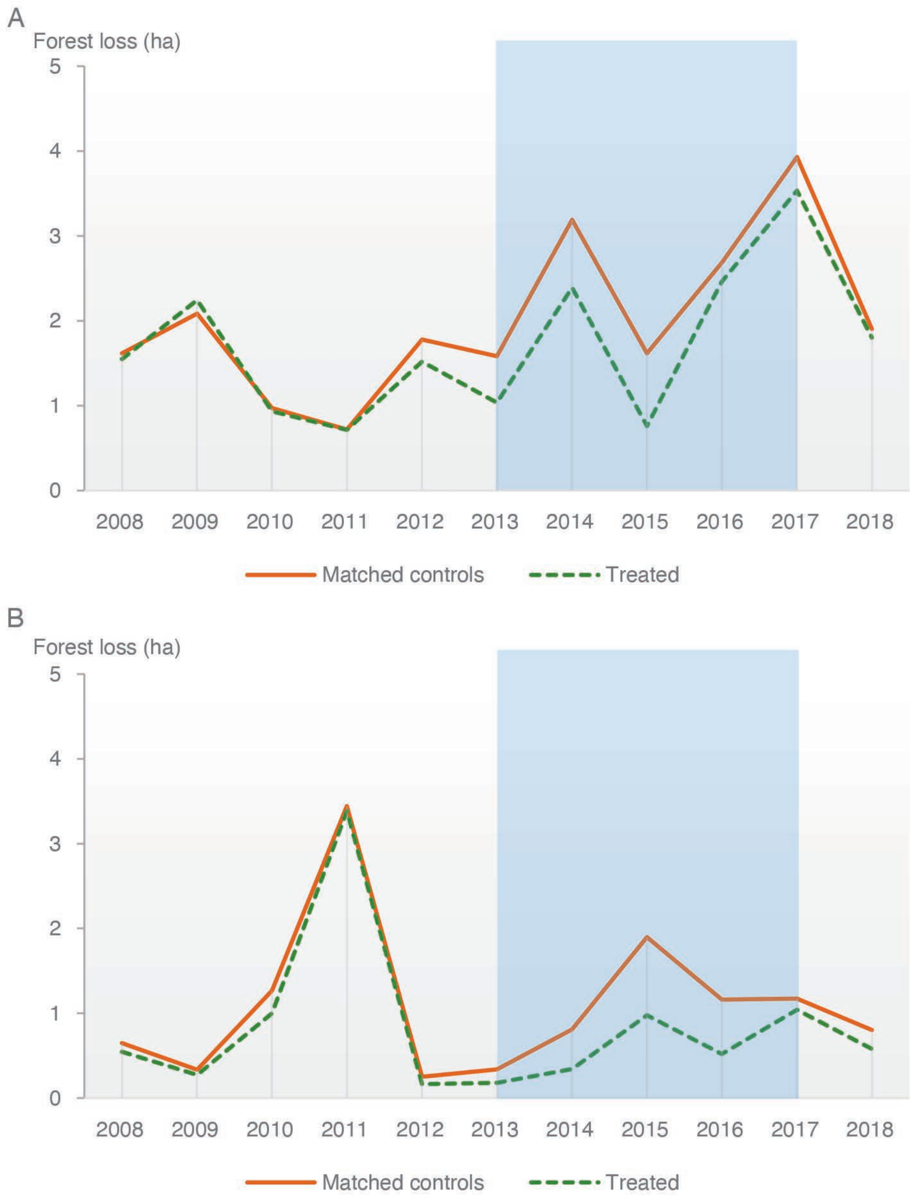

Figure 12.3. Impact of the Sustained Settlements in the Amazon programme on deforestation using GFC (A) and PRODES (B) datasets. The gap between the two curves indicates the impact of the Sustained Settlements programme (Source: Demarchi et al., 2020).

According to the GFC dataset, the participant group deviated significantly from the trajectory of the control group from 2013 to 2015. The same phenomenon was demonstrated with the PRODES data (with a one-year lag). Under the hypotheses made when constructing the control groups, this clear break in the deforestation trend among participants can be attributed to the Sustainable Settlements programme.

Permanence of REDD+ programmes' effectiveness

We also showed that the participants returned to a business-as-usual pattern at the end of the programme. It is interesting to point out that the environmental gain generated during the four years of the programme was not cancelled out by any catch-up behaviour. We failed to detect a significant impact of the programme for the years 2016, 2017 and 2018 using the GFC data or for the years 2017 and 2018 using the PRODES data. The participant group, whose trajectory had diverged from that of the control group, went back to the same behaviour after three years, which indicates that the impact became insignificant as the programme ended (Figure 12.3).

These results suggest that the gains achieved by the programme until 2018 represent a three-year delay in the deforestation that would have otherwise occurred without the programme. This means that we are in the scenario where the programme participants agreed to modify their behaviour for the duration of the programme, only to return to a business-as-usual pattern after the programme ended. This suggests that the intervention was not sufficient to trigger lasting change in farmers' behaviours. Additionally, we did not detect a higher rate of deforestation in the participating group than in the control group after the end of the programme, meaning that participants did not catch up on their postponed deforestation. Thus, the environmental gain generated during the three first years of the programme was not subsequently cancelled out, and it persisted at least until 2018 (when the analysis ended). This study describes a situation in which the effort to preserve biodiversity is not sustained when a programme ends, since it conflicts with the objective of food security for populations that fail to adopt diversified agricultural systems and remain stuck in agricultural systems based on the destruction of the forest resource.

Overall, the results of these different projects implemented in different regions of the world suggest that diversification strategies, whether for production systems or sources of income, can play a key role in the dual objective of preserving natural resources and guaranteeing food security. Indeed, it has been shown that the diversification of agroforestry-based production systems is likely to increase crop yields and reduce the vulnerability of households by improving their food security. It has also been shown that forgoing crop diversity and opting instead for monoculture can increase inequalities in access to the consumer goods market and thus threaten the food security of the most vulnerable households. Finally, we have shown that while mechanisms such as payments for environmental services may resolve the trade-off between natural resources and food security in tropical areas, their long-term effectiveness remains to be demonstrated.

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Chapter 13

Urban food waste: a resource for circular economy between cities and agriculture

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Until recently, urban food waste was considered a minor issue within the global food system. As cities grow, especially in Asia and Africa, this concern is receiving more attention from policymakers and scientists in terms of food system efficiency and food security (Guilbert et al., 2016). Estimates predict that by 2050, half of all food waste, i.e., that which comes from both retail and consumers, will be generated by urban systems (Parfitt et al., 2010). In particular, the mass of urban food waste is directly correlated to the urban population and constitutes 20% to 80% of municipal solid waste throughout the world (Adhikari et al., 2009). In response, major investments have been made in the last 20 years to boost treatment of food waste either on site or in landfills. However, to deal with the rapid growth of cities, the management of food waste requires additional technical and organizational innovations, in particular due to the environmental and sanitary risks related to those by-products (Westerman and Bicudo, 2005).

According to the FAO, 'food loss and waste refer to the decrease in mass (quantitative) or nutritional value (qualitative) of food – edible parts – throughout the supply chain that was intended for human consumption. Food loss is the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain (producers, processors). Food waste refers to the decrease in the quantity or quality of food resulting from decisions and actions by retailers, food service providers and consumers.' (FAO, 2011) This chapter focuses on urban food waste and the value of this organic waste for a formal or informal circular economy.

Food waste management can be addressed through three main levers: 1) more efficient agrifood value chain distribution, 2) human day-to-day consumption practices, and 3) the new circular economy. There is obviously a paradox in promoting the recovery and recycling of 'waste'. However, since a large part of this waste is essentially due to consumption patterns, this major component of food systems must be tackled. From a circular economy perspective, and given the need to make better use of organic biomass, urban waste must be viewed as a resource, especially for urban and peri-urban agriculture (Westerman and Bicudo, 2005).

Is it better to deal with the problem at its source by reducing waste from distribution and consumption, or should the transformation of waste recovery and recycling systems be initiated, through the circular economy, at the urban system level? Should solutions be designed globally, or adapted to each local context? This chapter gives some examples on how to address the issue of food waste in cities at different scales. We consider in particular the peri-urban fields, economic channels, school canteen networks, waste channels and experimental urban farms.

With examples from various cities such as Montpellier, France; Chicago, Ill., USA; Antananarivo, Madagascar; Dakar, Senegal; and Hanoi, Vietnam; this chapter follows food waste production and recycling at different steps of the food system: in wholesale and retail markets, stores, restaurants and households. A first case study deals with food waste in various cities with a common approach, while another project, 'Bidons Bleus' [blue barrels], focuses on a particular type of waste in a single city. Our study shows that coping with food waste using solutions to limit emissions or recycle materials involves numerous stakeholders, and especially small-scale recyclers, specialized in waste recovery and valorization. Some stakeholders try to innovate in order to reduce waste production or to improve the collection and transformation of this waste into an important resource for agriculture. Our results highlight that a circular economy based on food waste valorization already exists around the world, with some constraints related to sanitary regulations. Synergies between agriculture and cities are possible within the food system in order to manage food waste more efficiently. Actions to develop such synergies should be considered from multi-partner and multi-sector perspectives, taking into account the system's upstream and downstream sectors and the corresponding stakeholders, including retailers and consumers. Agriculture could be a solution for managing urban food waste if consumers and policymakers increase their awareness and support it.

⏩ How to reduce urban food waste by considering the circular economy?

Because of limited resources and energy sources, human activity should limit extraction from nature and promote economic efficiency. Waste is considered 'efficient' if the by-products generated from the consumption of extracted resources can be re-used or recycled instead of being lost for the community or for the environment. Re-using waste to produce new goods in a sustainable manner has two main interests: 1) environmentally, recycling may limit resource extraction for producing a new good and may benefit nutrient flows; and 2) economically, recycling can reduce costs and generate greater accumulation of wealth within the local and global economies.

The circular economy as a means to handle waste production

Closing the loop of the linear economy is a challenge for many countries that are in different development stages. Growing consumption in emerging and developing countries needs to be considered as the strongest trend in the twenty-first century within urbanization trends, energy transition and climate change. The circular economy is linked to the industrial ecology of material flows. Material flows between actors should be mapped to understand the system organization (such as in agrifood systems, industrial systems or service-based economies). When waste emissions are identified, experts can assess the value of waste and find new options to re-use and recycle it. The objective of the circular economy is to reduce the amount of material extracted from nature per unit of produced good or service.

From that perspective, we recognize the bioeconomy as a social project based on allocating the use of biomass towards more sustainable development pathways. In that sense, the bioeconomy refers to a particular model of managing physical flows through loops and recycling. In practice, our economies are already more circular than what experts may claim. Many stakeholders around the world, from both formal and informal sectors, earn their living from recycling various organic wastes. Depending on how circularity is defined (re-using and/or recycling), the global economy was even more circular during the nineteenth and twentieth centuries (Daviron, 2019). The tradition of waste pickers still represents an important side of urban food systems in developing countries. In more developed countries, waste management shifts from individuals to state services and private enterprises. The circular economy involves both technical dimensions (material flows, biomass and derived energy, etc.) and socioeconomic dimensions (management organization, diversity of stakeholders, social choices).

The circular economy for urban food waste management: a growing challenge

Since 2007, cities across the world are now home to more than half of the planet's inhabitants and play an important role within the global agrifood system. The growth of the urban population has highlighted the emergence of food waste as an environmental and economic issue (Guilbert et al., 2016). Food waste production is directly related to the concentration of a population, but it is also highly dependent on household living standards. Nearly 20% of the global population lives in large metropolises, yet these cities produce 40% of food waste. With 65% of the world's population estimated to be urban residents by 2050, food waste management will certainly become a major goal of the global food system, along with food and nutritional security (Adhikari et al., 2009).

When applied to food waste, the circular economy aims to prevent waste going to landfills and to promote innovation in re-use and recycling. Recycling food waste through the circular economy is particularly promising for urban and peri-urban agriculture, since waste constitutes a potential resource. Food waste can have value for agriculture, feed and energy production. The challenge is to find the recycling method that is most suited to each context. The circular economy can then contribute to the relocation of production by developing farms in peri-urban zones, reshoring jobs and decreasing the agrifood system's footprint. The links between city, food waste and agriculture often rely on formal and informal networks of the circular economy within the urban and peri-urban agriculture sectors (Borrello et al., 2017). Urban and peri-urban agriculture are globally important drivers for managing solid urban organic waste. They could be among the future central players for increasing the sustainability of cities.

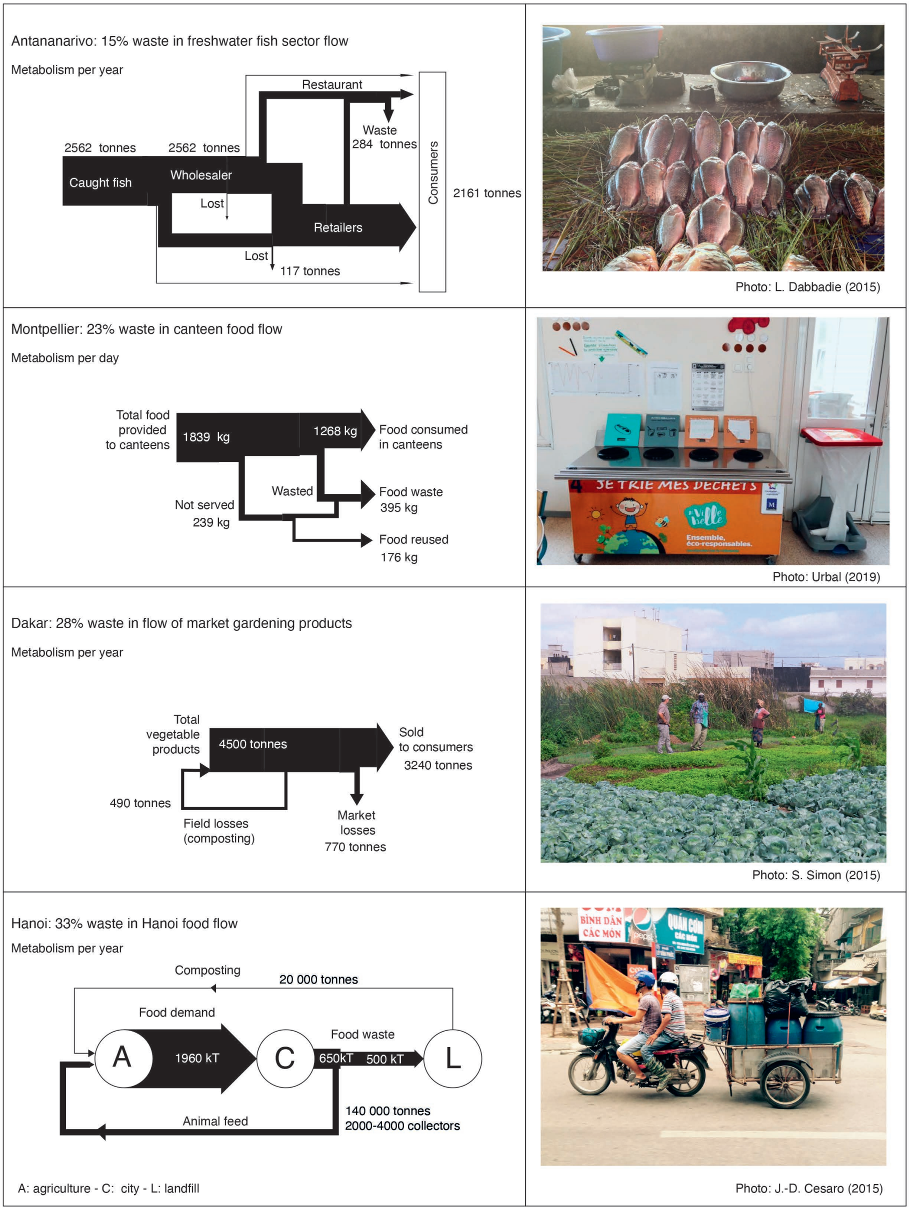

Figure 13.1. Flows of food and food waste in four cities around the world.

⏩ Territorial metabolism: a method to quantify and qualify urban waste

We have attempted to quantify the flows of food materials and food waste in different systems: 1) urban agriculture in Dakar (Senegal), 2) freshwater fish marketing channels in Antananarivo (Madagascar), 3) school canteens in Montpellier (France), 4) an industrial ecology centre founded in Chicago (USA) to maximize flows within the various agrifood activities, and 5) the urban food waste landfills in Hanoi (Vietnam). These very diverse case studies present contrasting situations of variable regulations, different masses of waste and disparate solutions to manage it.

Visualization and systemic analysis of food and food waste flows

The flow analysis findings from the five case studies are presented in Figure 13.1. The figure shows the evolution of proportional flows between agriculture (Antananarivo, Dakar, Hanoi) or food processing (canteens in Montpellier, a company in Chicago) and the purpose of the system, namely the final consumer for sector approaches (Montpellier, Antananarivo, Dakar) or landfill for circular economy analysis (Hanoi, Chicago). Two of the cases have a rather linear economy (Montpellier, Antananarivo). In three cases, material loops are highlighted (Dakar, Hanoi, Chicago). Only two cases (Hanoi, Chicago) are clearly targeted at the circular economy, in the sense of exchange between economic actors. In Madagascar and Dakar, the circular economy seems to be implicit within the waste trade but has not been studied. Food waste represents about 20% of the volume in each case and appears at different levels depending on the studied system.

Food waste in cities in the Global North: from public regulation to collective innovations

The Montpellier and Chicago case studies focused on the analysis of two organizations:
– school canteens in Montpellier (France);
– an experimental industrial ecology centre called 'The Plant' in Chicago (USA).

In Montpellier, the survey included 18 school canteens supplying 3200 meals per day to nursery and elementary schools. Two central kitchens prepared the meals that were then delivered by a catering company. Two types of food delivery systems were in place: hot or cold, depending on the equipment available in the canteens for reheating. In order to assess the level of waste, the method consisted in weighing the food arriving at the canteen (input) for two weeks. Two major food categories were considered: food served to children and food not served. All food waste was weighed at the end of the day.

These results showed that a significant volume of food was wasted. The total food received by the canteens was 1839 kg per day. Children consumed 69% of food delivered and produced 15% of food waste. Some 14% of food delivered was not served. The staff recovered almost half of the food not served, either for the children's snacks or for themselves, and the rest was thrown away. The total food waste was 422 kg per day, which represented 77 tonnes per year (182 school days). The catering company was well aware of the economic impact of food waste, since it had to pay twice for this waste: the purchasing price of the food supply that was not consumed, and taxes for urban waste collection services. French regulations encourage catering companies to donate unconsumed food in accordance with hygiene and cold chain standards. The staff can take home some of the unserved products. For food waste, local composting is preferred if there has been no contact with food of animal origin. Staff collect some waste for pets or household livestock production for their own use.

In Chicago, The Plant is an urban project to support industrial symbiosis between different production start-ups (mushrooms, algae, insects, honey, aquaponics, anaerobic digestion, among others) and marketing of products (direct sales) (Chance et al., 2018). The Plant hosts and collaborates with various companies to promote an inter-company operation in the framework of industrial symbiosis.

The work focused on studying the flows and exchanges of materials and energy between the partners of this industrial symbiosis and then monitoring the fate of two or three selected productions until consumption. It consisted in:

– developing a global vision of the whole system and the flows and exchanges between the different projects hosted in the industrial symbiosis;

– analysing more specifically a type of product and measuring local food waste at the distribution level. Material flows were monitored for three weeks, through three bread productions, and thus three deliveries per week. Losses were monitored both at the bakery and various points of sale (The Plant's site, the local market and four retailers in Chicago).

The three largest material outflows were the materials directly re-used on site (21 tonnes), those used at the landfill (19 tonnes) and those sold off-site as goods (15 tonnes). Although the quantities of waste going to landfill and sold goods were composed of small and multiple streams, nearly 98% of the materials tracked through the system were composed of brewery co-products. The anaerobic digester was not yet operational at the time of the survey. When it is operational, it should be able to process 12 tonnes per day of biowaste, which will be an important source of compost for urban agriculture and natural gas for energy.

The application of the material flow analysis methodology to The Plant provided both global and targeted views of certain streams (Mulrow et al., 2017). The data collected on material flows and their materialization is useful to improve the symbioses between the site actors, but also to reduce losses and waste and to better plan the future (Figure 13.2). Some specific authorizations were issued for the first time to respond to the need for innovation, such as the authorization to breed animals for human consumption indoors, within the aquaponics system (Nogueira et al., 2020).

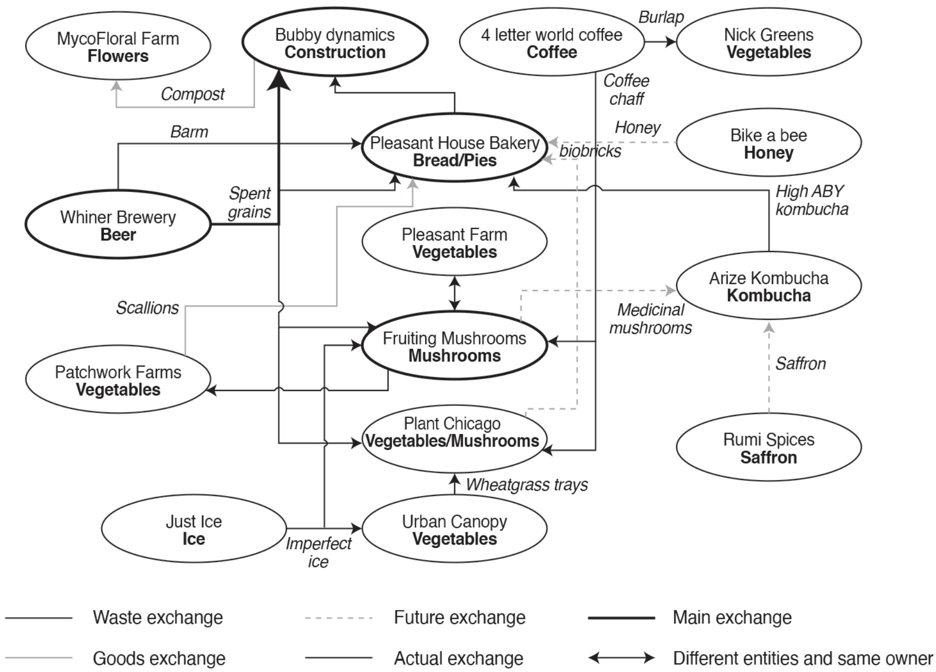

Figure 13.2. Material flow between the different projects and activities within 'The Plant'.

Food waste in cities in the Global South: the importance of informal practices

The case studies of Antananarivo (Madagascar) and Dakar (Senegal) focused on analysing two parts of the food system:
– the lake fish value chain providing fish to Antananarivo market;
– urban agriculture and marketing around Dakar.

In Madagascar, the study involved identifying the actors and stages of the freshwater (lake) fish distribution chain and quantifying, for each type of actor, the volumes purchased, sold and stored, as well as the volumes of waste. The study also aimed to extrapolate these volumes to the urban system of the capital city and map the flows and materials.

Using official data, we estimated that 2562 tonnes of lake fish were sold in Antananarivo annually. According to a survey downstream of the value chain, the waste resulting from the marketing and consumption of this fish was produced mainly by restaurants (284 tonnes), and by retailers and wholesalers (117 tonnes). These figures only took into account fish that had not been consumed. Direct food waste accounted for 16% of fish weight and was due to downgrading of fish for quality reasons. However, the study concluded that 50% of the weight of consumed fish was wasted. The waste biomass resulting from fish was partially recovered. The lake fish value chain produced

400 tonnes of direct food waste (fish not consumed) and 1,000 tonnes of by-products. Most of the waste ended up in landfills while the rest was re-used. It was difficult to precisely assess the use of fish carcasses in animal feed. Restaurants and traders gave this waste to itinerant collectors or sold it as animal feed.

In Dakar, nearly 62,000 households, i.e., about 14% of the population, work in urban agriculture. In the early 2000s, peri-urban horticultural production occupied more than 34% of the land area and accounted for nearly 40% of the production of horticultural products for the national market (Smith, 1999). To our knowledge, the current contribution of urban agriculture to the urban supply has not yet been studied in the literature. The food distribution network was particularly dense, with neighbourhood stores, daily markets and kiosks that allowed Dakar residents to purchase food without travelling long distances. This system has not been studied in detail and post-harvest losses and food waste have never been quantified. The study focused on two sites:

– Pikine Ouest, with 42 ha and 384 farmers. The productions monitored by the project were lettuce (about 3500–4000 tonnes/year, spread over the whole year), bitter eggplant, tomato, bell pepper and cabbage. Irrigation was carried out with a mixture of wastewater and underground water.

– Patte d'Oie, with 7 to 12 ha actually farmed and 280 farmers. The productions followed were lettuce (about 500 tonnes/year, distributed all year long), bitter eggplant and tomato. Irrigation was practised with a mixture of 'treated' wastewater from the sewage plant and underground water.

Post-harvest losses from gardening and product losses at market were estimated at around 10% with a marked seasonal effect, especially in the hot season. An average of 18% of bell peppers were lost in the field or at market. The total losses exceeded 28% in the hot season. On average, the production of losses and waste exceeded 400 tonnes in the Pikine area, which was relatively high. All post-harvest losses at gardening stage were returned to the soil in the form of compost. For losses at market, the landfill rate was very high: recycling of materials was rare, and the return for agriculture was virtually non-existent. A few livestock breeders located near landfills recycle vegetable losses into animal feed.

The production of food waste at the consumer level and losses throughout the value chain were quantified in the four case studies analysed. Territorial metabolism proved to be a very useful method to quantify and qualify urban waste. The volumes disposed of as waste varied among the horticulture, fresh fish and canteen value chains.

In a complementary approach, the practices of food waste re-use and recycling for livestock husbandry were reviewed in Hanoi, Vietnam. The purpose was to document an informal food waste recycling practice through animal feeding in Hanoi, and to assess its potential for sustainable development of urban food systems.

⏩ Recycling urban food waste through animal husbandry

The use of food waste in Hanoi, Vietnam, by pig breeders was reviewed to assess its potential for the sustainable development of the Hanoi food system. Technical and sanitary problems related to this informal business were also reported.

In Vietnam, urban food waste is part of a traditional relationship between city and intra-urban livestock systems. Farmers living on the outskirts of cities are used to coming every day to collect organic materials to feed to their livestock. Individual households and collective catering institutions also contribute to these recycling practices by giving away or trading their food waste with their neighbours who raise pigs. However, in the current context of urban growth and livestock sector industrialization, this type of traditional food waste management seems to be in decline. Today, food waste is transported in blue barrels over longer distances to livestock farms that were pushed out of the city by sanitary regulations.

Urban food waste recycling through pig feeding: a traditional activity

In Vietnam, since the beginning of the 1970s, many peasants living on the outskirts of large metropolises like Hanoi and Saigon used to buy urban kitchen scraps, also called swill, for pig feeding (Tran The Tong, 1973). This informal organization was seen as useful in the post-war subsistence economy. After the Đổi Mới economic reforms that started in 1986, the administration set up formal management of urban waste which contributed to the marginalizing of these small-scale collectors (Dao Ngo, 2001).

With urban sprawl and demographic growth, peri-urban agricultural and livestock activities have been decreasing. Agricultural belts are becoming unstructured and moving away from the city centre (Sautier et al., 2014). Livestock breeders using food waste try to maintain some proximity to city centres, although they are located in the city outskirts or in interstice areas.

Dao Ngo (2001) estimated that at the end of the 1990s, informal recycling of municipal solid waste carried out by farmers reached around 14% of total Hanoi municipal solid waste. However, he pointed out that farmers would also recover other materials, such as human waste. He believed that the maximum recycling rate likely reached 30%. Farmers could recycle between 65,000 and 140,000 tonnes of food waste per year at that time.

Takaaki et al. (2012) estimated that the recycling rate of food waste in 2009 was around 6.5% in Hanoi. We consider this rate to be the lowest estimate. For the high estimate of 2015, we have retained the rate of 22% provided by the planning department of Hanoi province. Livestock farmers could recycle between 40,000 and 140,000 tonnes of food waste in 2015.

The new business of urban food waste recycling

Despite the decrease of peri-urban livestock activities, the number of breeders interested in waste was high, leading to competition among them. The resource has been gradually transformed into commodity. ‘In the past, food waste was often free, now it’s becoming a business’ (interview with a breeder by Gia Lâm, 2016). Because this management became a ‘business’, the requirements of breeders were more demanding regarding the quantity and quality of urban waste.

According to the survey conducted between 2015 and 2016 (Cesaro et al., 2019), the collectors harvested food waste from restaurants (75%), corporate and school canteens (22%), households (11%), hotels (8%) and markets (4%). On average, the waste producers (mostly restaurants) produced 30 kg of food waste per day. Households produced much lower volumes. The average composition of food waste was rice and noodles (58%), vegetables (18%), meat (8%), fish (6%), bones (5%) and other (4%). To transport this food waste, 85% of the collectors drove a motorcycle, 10% a truck and 5% a bicycle. Those who collected waste by truck were more organized and able to collect larger quantities. Those on bicycles logically looked for proximity with urban pig breeders. Collectors used several types of blue barrels, ranging from small barrels of 20 litres to very large barrels of more than 200 litres.

Based on data from the 2001 and 2011 agricultural censuses, the rapid decrease in the number of peri-urban farmers raising at least one pig per household in a radius of 30 km around Hanoi was confirmed. We estimated that there were around 4,000 blue-barrel collectors in 2016, accounting for around 40% of breeders within a 10 km radius, but only 4% within a 30 km radius. At 30 km from Hanoi, there were other large cities and industrial areas providing food waste to surrounding breeders (Cesaro et al., 2019).

Health and epidemiological risks related to the informal sector

Raising animals in cities, especially in densely populated areas, leads to severe constraints and high risks in terms of environmental pollution and impact on the population health. The conditions of pig farming by peri-urban breeders vary greatly. We identified three types of livestock farms in the Hanoi suburbs.

– Farms in a constrained urban environment. These were areas where agricultural plots were non-existent. The health and environmental risks associated with management of livestock manure were high. This kind of breeding was common in the middle of outlying urban districts.

– Farms in agro-urban interstice areas. These farms benefited from the preservation of certain agricultural areas in urban space, particularly along the banks of the Red River or in flood-prone areas left for market gardening or arboriculture. The health and environmental risks were lower on these farms.

– Farms in rural areas on the edges of towns/villages. The location of these pig farms gave the farmers an advantage for managing pig effluents thanks to the direct access to agricultural plots or lakes.

The pressure of livestock farming on urban environmental resources led the authorities to develop programmes for the relocation of livestock from town to villages, within intensive farming areas (Cesaro et al., 2018).

The epidemiological study identified three types of sanitary hazards for pigs: physical, chemical and biological. The typical sign that was mentioned for pigs affected with a physical hazard was fever caused by swallowing toothpicks. The risk of chemical hazards was higher due to food waste contaminated with dishwashing liquid.

Regarding biological hazards, the risk was low because all farmers used cooked food waste (Duong et al., 2017).

The recycling system has been recently dealing with new epidemiological and health constraints. The first constraint (epidemiological) is linked to the spread of African Swine Fever (ASF) in China and later in Vietnam in 2018 and 2019. According to the FAO, 'local government authorities have been implementing strict movement control of pigs and pig products from infected communes, mobilising their resources for pig culling and disposal, small pig farming models with low biosecurity and swill feeding still continue to facilitate ASF spread.' (FAO, 2019). Unlike China, Vietnam opted for a less restrictive approach and let breeders operate with good practices and the limitation on marketing of pigs outside production regions for small producers. The second constraint (health-related) was the COVID-19 pandemic and the implementation of containment measures. Because restaurants were closed, collectors no longer had access to their main resource. Breeders then sold their pigs in massive numbers. Some turned to more conventional farming systems. With the re-opening of businesses, the breeders and collectors resumed their activity, but with the worry of being vectors of disease.

⏩ Conclusion

Urban food waste represents an interesting resource for agriculture. It is used for energy generation in fermenters and as organic fertilizer, industrial materials or animal feed. Some recycling practices exist in many cities in the Global North and Global South and offer interesting alternatives to promote the circular economy between cities and agriculture. However, these practices are still limited and measures encouraging the recycling of urban food waste may conflict with the main stated objective of current public policy, i.e., preventing food waste by reducing it at the source. It remains difficult to industrialize urban food waste collection without impacting the organic quality and agricultural potential of this material. Moreover, regulations often limit recycling flows because of sanitary risks. As a result, only a small fraction of landfilled quantities is recycled, especially in the Global North where informal practices are strongly regulated.

Expanding the application of the circular economy to urban food waste will require financial investments, technical innovations and organizational solutions. The sustainable development of urban food systems is heavily dependent on being profitable. But addressing the issue of food waste in cities is not just a matter of investment, organization and technological innovation. It is mainly a multidimensional issue that requires specific solutions to respond to specific problems and contexts, notably to urban morphologies and sociologies. Efforts to reduce food waste at the source on the one hand, or recycling on the other, must be considered in conjunction with the diversification of food systems, the development of the circular economy and the growth of participatory economies based on informal systems. Multi-stakeholder platforms are needed to identify the appropriate collective choices to be made in each context. Recycling urban food waste remains a major challenge for the common future of cities and agriculture. Due to the world's rapid urban growth, this challenge will become increasingly important in the coming years.

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Chapter 14

Market gardening for African cities: contributions, challenges and innovations towards food security

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In many African countries, vegetable production has significantly increased since the early 2000s (FAOSTAT, 2016). This increase results from a rising consumer base as well as a greater share of vegetables in households' diets and budgets (Chauvin et al., 2012; OECD/FAO, 2016). The development of market gardening is particularly salient in peri-urban contexts. Vegetable production spreads within or in the outskirts of cities both large and small due to the products' perishability and difficult transport conditions (high transport and storage costs, lack of or poor cold chain and transport infrastructure). Market gardening also offers clear advantages for producers living in urban and peri-urban areas. Producers in peri-urban areas can make use of small agricultural plots, earn income on a short-term basis, combine agricultural production with off-farm activities, and more easily access both input and product markets. However, this type of market gardening development is challenged by growing land pressure, competition for access to water, and the use of increasingly expensive imported chemical inputs along with rising citizen demands regarding environmental and health issues.

Market gardening can directly and indirectly support urban and farm households' food security (through consumption for the first, and through self-consumption, incomes and jobs for the latter). Nevertheless questions arise regarding the sustainability of market gardening and the levers to promote its contribution to food security.

This chapter briefly presents the results of three projects funded by the GloFoodS metaprogramme between 2017 and 2019 (see Acknowledgments section). It addresses three questions linked with food (not nutritional) security. First, what is the effective contribution of intra- and peri-urban market gardening to urban food security for both producers and consumers? Second, how does vegetable production evolve with regard to land competition and social pressure to reduce negative environmental effects? And third, what are the technical and institutional innovations that are both relevant in agronomic and economic terms to reduce the use of inputs (chemical and organic) that are harmful to the environment and health?

This chapter examined case studies of market gardening at different scales in four African countries: the territory level in Madagascar, the farm level in southern Benin, and the plot level in Tanzania and Senegal. The analysis combines different disciplines (economics, geography, agronomy, etc.) and methodologies (analysis of satellite images, quantitative and qualitative surveys, analysis of value chains, agronomic experiments in stations and on farm, etc.). The examples provided are significant, although not exhaustive, considering the huge diversity of market gardening systems in Africa.

⏩ Contribution of market gardening to food security

Contribution to urban consumers' food security

Agricultural belts are known to often crop up near or around African cities (Moustier and David, 1996; Moustier and Renting, 2015). In the agglomeration of Madagascar's capital city, with a population of more than three million, this belt is particularly marked. In a perimeter of about 30 km around the city centre, 45% of the land (34,000 hectares) is still cultivated with rice, cassava, arboriculture and market gardening (the latter occupies 8% of cultivated land, about 2,700 hectares) (Dupuy et al., 2020). Thanks to this proximity and area, intra-urban and peri-urban market gardening plays a key role in urban households' food security in Antananarivo in terms of regularity, quantity and diversity of supply. It also provides produce to the Malagasy capital during the off-seasons of other production areas of the country and covers a large part of the urban market for vegetables (from 30% to 100% depending on the crop) (Defrise et al., 2019). Market gardening offers consumers a large range of products that has been increasing over the years (introduction of cauliflower, broccoli, asparagus, etc.) (Aubry et al., 2012). In Senegal, since the 2000s, the Niayes region, a coastal strip stretching from Dakar to Saint-Louis, provides 80% of national market gardening production and covers 60% of the capital's demand (Ba and Moustier, 2010). In south Benin, the vegetable sector supplies local markets as well as the main markets of the neighbouring countries: those of Accra in Ghana, and Lagos and Ibadan in Nigeria (PADMAR, 2015). However, in terms of food security and food safety, market gardening also comes with some drawbacks. First, the accessibility of products is limited by the extreme household poverty levels, despite relatively low prices in local markets. Second, the food safety of products and their environmental impact raise many questions due to the use of non-authorized chemical inputs, as well as misuse of inputs (over-dosage, post-harvest treatment on products, etc.) (Madagascar: Aubry et al., 2012; Senegal: Ba and Moustier, 2010; Benin: Assogba-Komlan et al., 2007) and wastewater irrigation (Madagascar: Dabat et al., 2010).

Contribution to urban producers' food security

Food production generally, and market gardening in particular, contributes to the food security of producers' households. In Antananarivo, one household in five is engaged in agricultural activities (full or part-time), either due to a lack of alternative job opportunities or as part of a diversification strategy (Defrise et al., 2019). Market gardening is a source of direct jobs[25] from which the income generated could potentially improve access to food.

In south Benin, one hectare of market gardening generates between three to four full-time equivalent jobs, with the investment in labour covered by farmers (30%) and workers (70%) (Avadí et al., 2020). The socio-economic profile of producers reveals that they are of all ages, and may be locals or migrants, and men or women. Although market gardening is more risky than growing other agricultural crops (due to climate, pest pressure, perishability) and comes with substantial expenditures (seeds, fertilizers, treatments), it is a profitable activity for producers with access to small plots, irrigation water and markets (inputs and products). It generally offers quick monetary returns (thanks to short production cycles), is frequently off-season compared to main staple crops, and the margin per hectare for market gardening (more systematically than the remuneration per working day still for market gardening) is generally higher than for other crops (cereals, legumes, etc.) (Schreinemachers et al., 2018). These regular cash contributions and the consumption of unsold products within the household thereby contribute to producer household food and nutrition security.

In the agglomeration of Antananarivo, the producers use from 5% to 12% of the volume of their production for self-consumption (green onion: 4%, tomato and carrot: 7%, green bean: 8%, green pea: 10%, leafy vegetables: 12%) (survey on 634 households, in Defrise, 2020).

⏩ Evolution of production systems and reduction of environmental impacts

Evolution of production systems due to land pressure

Although vegetable production systems are subject to various pressures, they are still continuing to spread. In the agglomeration of Antananarivo, like in many capitals, urban area is expanding as agricultural area decreases (3.2% per year) (Defrise et al., 2019). Quite unexpectedly, despite this agricultural area[26] reduction, cultivated area is also expanding. Built-up and cultivated areas are simultaneously expanding as pasture, rangeland and wasteland are decreasing (Defrise et al., 2019). This progression of cultivated area results in part from the flexibility of market gardening systems. In the agglomeration of Antananarivo, where public policies on urban agriculture are virtually absent, but where demand for vegetable products is growing, different factors contribute to the development of market gardening according to the area (Defrise et al., 2019). Where population and urban densities are high (5,000 to 40,000 inhabitants per km^2), the increase in built-up land limits the area of cultivated plots, alters access to water and organic matter, and forces farmers to intensify their agricultural practices in terms of labour and capital. Moreover, wastewater runoff contributes to the over-fertilization of plots, which damages rice production (growth of tillers to the detriment of the grain), but benefits leafy vegetables, especially watercress (Dabat et al., 2010). Finally, land tenure insecurity encourages producers to cultivate their land year-round, and market gardening contributes to this territorial marking. However, when land pressure becomes too strong, market gardening disappears in favour of buildings

25. It is also a source of indirect jobs (collectors, transporters, and resellers).
26. Agricultural area includes cultivated and non-cultivated area, such as pasture, rangeland and wasteland.

and infrastructure (including new roads in the lowlands to open up the city). Where population and building densities are lower (300 to 1000 inhabitants per km^2) in the agglomeration of Antananarivo, the development factors for market gardening differ (Defrise et al., 2019). Buildings develop on the hilltops, whereas market gardening takes place in the lowlands in the off-season, and on the hill slopes in season. Farmers inherit small plots and struggle to buy lowland (opportunities to buy lowland, dedicated to rice, are scarce and land prices are high). Thus, they are forced to progressively develop market gardening at the base of the slopes, on family land obtained through the reactivation of land rights, or on cheaper, lower-quality land.

In Senegal and Benin, market gardening in the capital cities has disappeared to make way for urban services (housing, office, roads, etc.) (Benin: Alinsato and Yagbedo, 2018). In the Niayes region of Senegal, market gardening is still going strong despite considerable urban sprawl (up to 5.5% per year) (see Figure 14.1, map by Jolivot, 2021). The practice is experiencing a dynamic of relocation and expansion. As we observed it in Antananarivo, cultivated areas are expanding and areas dedicated to market gardening and orchards are developing (up to 300 ha per year) (Figure 14.1), and innovative methods such as micro-production on roofs or in building courtyards are also becoming more widespread (Ba, 2007; Ba et al., 2018). This growth is driven by household food needs and profitability (farmers and urban elites invest in this activity). As a result of population growth, built-up areas and irrigated agriculture, water resources are increasingly used and, according to current hydrogeological models, becoming depleted (DGPRE, 2014).

Evolution of production systems towards the reduction of environmental impacts

In general, three main types of vegetable farming systems coexist in the different countries mentioned above. The first type of system is referred to as conventional, and is based on the use of organic and mineral fertilizers and chemical pesticides. These systems generally predominate in terms of cultivated area and number of households. The second type may be called 'lean'. These systems use chemical inputs but aim to control the input quantities and the quality of agricultural practices (timing, dosage, appropriate equipment) for financial reasons. The third type refers to organic farming systems, or those engaged in agroecological transition. These systems use only natural inputs (i.e., organic fertilizers and biopesticides) and avoid the use of chemical fertilizers and pesticides (or, in the case of agroecological transition, they are in the process of phasing them out). In practice, there is a productive continuum with conventional and organic farming systems at both ends, and many other systems in between, such as lean systems. In Benin, Senegal and Madagascar, the number of market gardeners exploiting organic and agroecological transition systems is still small,[27] and often certification occurs under participatory guarantee systems[28].

27. Those who have adopted these systems belong respectively to the network Association pour le Maintien de l'Agriculture Paysanne (AMAP-Benin) and the Fédération Nationale pour une Agriculture Écologique et Biologique (FENAB-Senegal).
28. The group of producers controls and guarantees the production on a peer to peer basis and according to different specifications. Thus, they do not have to resort to an expensive and complex third-party certification.

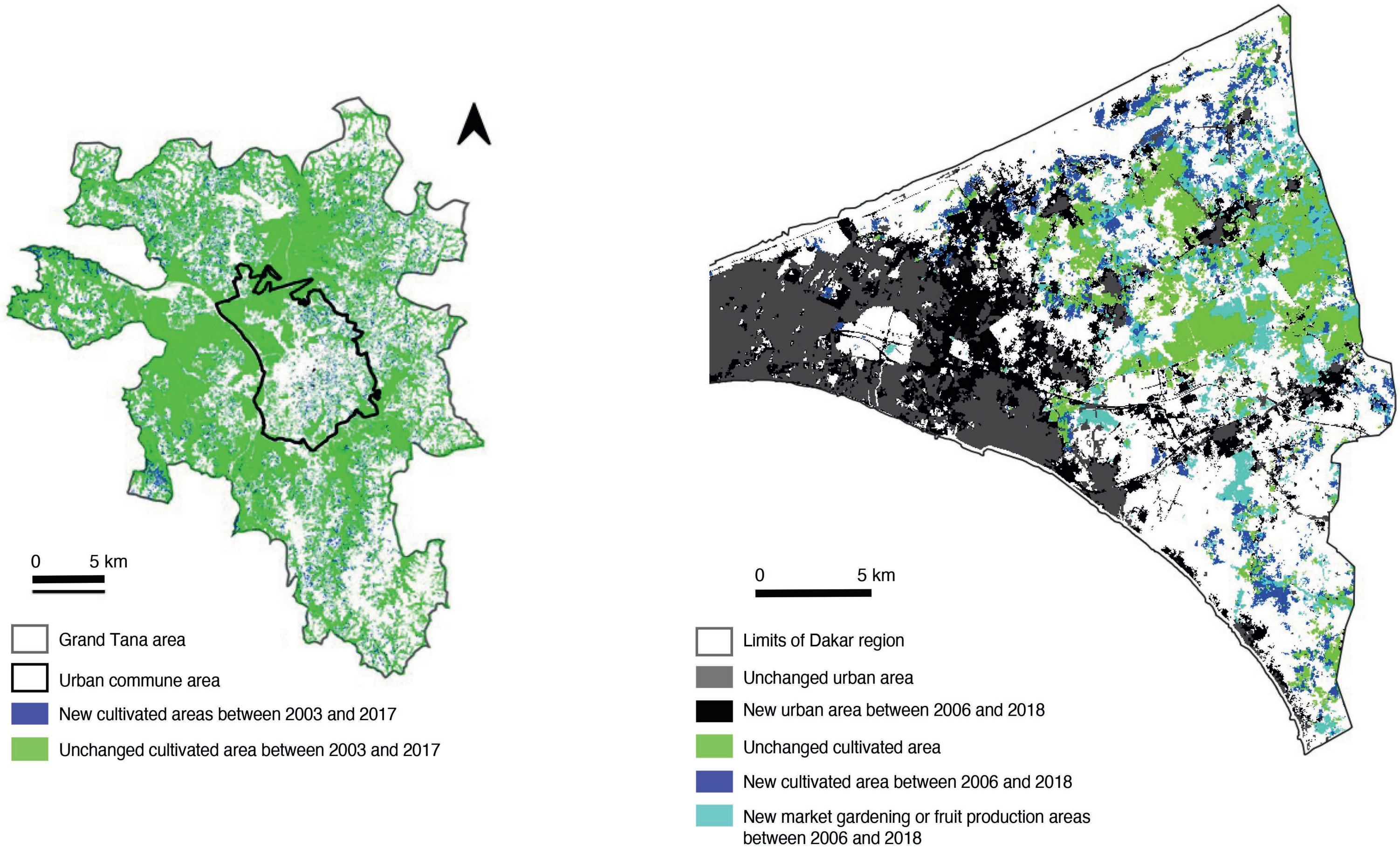

Figure 14.1. Evolution of cultivated area in the agglomeration of Antananarivo (Madagascar, left) and irrigated area in the Dakar region (Senegal, right). Source: for Madagascar, based on Dupuy et al., 2020; for Senegal, created by Jolivot, 2021.

In Tanzania, a fourth type of farm focused on exporting to the European market and complying with EU regulations (e.g., green beans) also exists. The necessary proximity to an airport contributes to its development in peri-urban areas.

Several factors account for the differentiation of production systems and, in particular, the development of organic and agroecological transition systems. Some factors influence the demand for organic products, such as greater awareness among consumers and producers regarding environmental and health issues, or the emergence of more profitable niche markets and shorter supply chains. Other factors influence supply, such as the increase in the cost of imported inputs, campaigns to raise producers' awareness of the dangers of pesticides, and in African contexts, the lower difference in terms of yield between organic/agroecological transition systems and conventional agriculture for fruits and vegetables than for cereals (De Bon et al., 2018). Finally, some factors modulate supply and demand jointly, such as advocacy and training provided by civil society organizations (agricultural development NGOs, consumer associations, specific markets).

A difficult trade-off between social, economic and environmental impacts

In southern Benin, the impacts of different production systems, located at three different sites, were analysed using life cycle assessment (LCA) and a selection of socio-economic indicators, based on a sample of 69 production units and a set of crops of interest (carrot, tomato, leafy vegetables, and cucurbits) (Figure 14.2). For the LCA, all inputs (resources consumed) and outputs (products, waste, emissions) per ha of vegetable production were considered (see Avadí et al., 2021, for more details).

Two main results were obtained. Firstly, for all crops, the differences between the environmental impacts of conventional and lean systems are not statistically significant (Figure 14.2). However, the differences are significant between conventional/lean system types and organic systems. Organic systems produce lower yields, and due to a limited price differential, generate lower revenues than conventional systems. Moreover, and counterintuitively, organic systems required less paid work than conventional systems, probably due to higher levels of family work associated with the former. Moreover, contrary to all expectations due to the absence of chemical inputs, organic systems generate larger negative environmental impacts. This is explained by the fact that farmers tend to apply excessive amounts of organic fertilizer to offset yield losses on sandy soil, which generates direct field N emissions, for instance (e.g., Perrin et al., 2015).

Secondly, environmental differences among farms within the same production system type (conventional, organic and lean; not represented at all sites), and even among production sites (Ouidah, Sèmè-Kpodji and Houéyiho), are also substantial. Differences are explained by the technical level of irrigation, fertilization practices, types of crop rotations and the association with crops with phytosanitary value (e.g., lemongrass), as well as by different soil characteristics, etc.

Trade-offs between negative and positive impacts can be addressed, for instance, on the basis of the priorities of authorities (local, national). If the main goal is to improve socio-economic conditions, systems that maximize these elements should be promoted, but if the objective is to minimize environmental impacts, systems with lower impacts should be favoured. From a sustainability point of view, one should seek Pareto optimality, i.e., systems where no dimension of sustainability can be improved without degrading another.

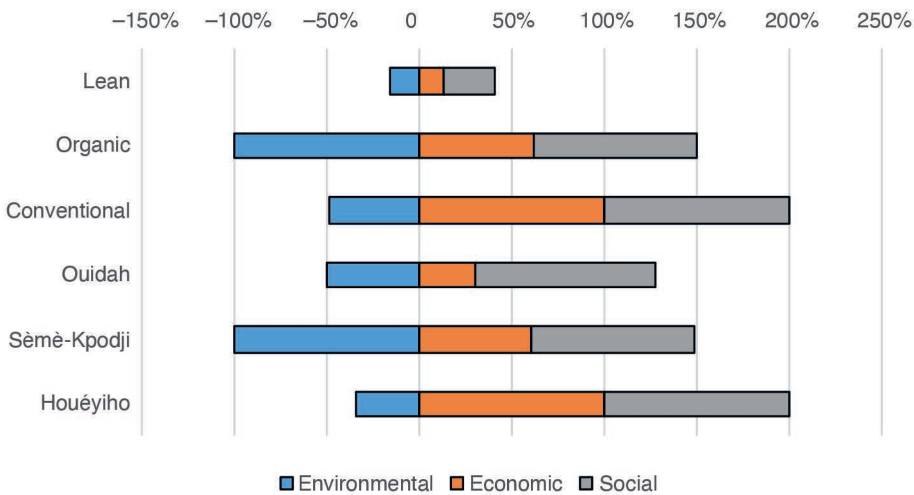

Figure 14.2. Comparison of the sustainability of market vegetable gardening systems in southern Benin, by type of production system and by production site (positive socio-economic and negative environmental impacts). Source: Avadí et al., 2020.

⏩ Innovation paths of market gardening

Agronomical innovation

Reducing the environmental and health impacts of market gardening involves supporting farmers, as underlined in the case of Benin for better management of organic fertilization. This also implies innovations to 1) have reliable and inexpensive tools to monitor soil composition, 2) drastically reduce the use of chemical pesticides to fight against flying and soilborne pests, and 3) encourage the sound use of local organic residues as a substitute for imported mineral fertilizers. This both restores soil health and reduces dependence on imports. The key factor for farmers to develop agroecological practices is the possibility of limiting production costs.

With regard to fighting flying pests (e.g., locusts), an alternative is the use of reusable insect nets. In Tanzania (Table 14.1), this technology, tested by 50 market gardeners on locally manufactured bamboo tunnels, led to 1) a gain in cabbage yield for all producers (between 17% and 44%, depending on the season), and 2) a marked reduction in pesticide use (2.8 to 3.5 times fewer applications; Nordey et al., 2020a, 2020b). In Senegal, this technology, adapted to locally manufactured shelters made from concrete reinforcing bars (materials available locally), has also resulted in reduced pesticide use and increased yields (for cabbages in particular). However, to prevent the proliferation of very small insects that can pass through the netting (e.g., aphids), it was necessary either to open the nets three days a week to allow in natural enemies (e.g., local ladybugs), or to release locally-reared natural enemies (e.g., *Nesidiocoris tenuis*).

Table 14.1. Comparison of the number of pesticide applications in Tanzania between production methods. The data are averages ± standard deviations. Different letters indicate that there were significant differences ($p<0.05$) between the traitements (from Nordey et al., 2020, courtesy of Crop protection).

Season	Treatment	Number of pesticide applications	Number of fungicide applications
1	Tunnel + reusable insect net	1.9 ±1.2 b	0
	Open field	6.2 ± 1.6 a	0
2	Tunnel + reusable insect net	1.5 ± 0.6 b	2.9 ± 0.8
	Open field	4.3 ± 1.1 a	3.0 ± 0.8

With regard to preventing root-knot nematodes (major soilborne parasites in market gardening), an innovation comprising two application methods was tested in Senegal at an experimental station field plot. This innovation consists in introducing annual legumes that control nematodes in the cropping system. With the first method, based on the use of these plants in rotation during the rainy season, two varieties of groundnut and three species of rattlebox (genus *Crotalaria*) were introduced. *Crotalaria* have been shown to be effective in controlling *Meloidoygne sp*. nematodes at the population level both in bulk soil and in the roots. Two of the three rattlebox species (*C. spectabilis* and *C. retusa*) have also, in addition, controlled other species of plant-parasitic nematodes (e.g., *Pratylenchus, Tylenchorhynchus* and *Ditylenchus*). In the case of *C. retusa* in a previous crop, tomato roots were completely free from galls three months after planting and the fruit yields were higher (using natural fallow as a control, and in comparison, with groundnut as the precedent crop). The second method was to combine eggplants with these same nematicidal plants, the association being directed at producers who were unable to perform a sanitizing rotation during the rainy season. This combination has been shown to be very effective in controlling *Meloidogyne sp*. and more efficient than the standard chemical treatment (MOCAP® EC). To avoid lower eggplant yields, the tests concluded that two sanitizing plants per eggplant offered the best compromise between nematode control and crop yield, compared with the control.

Regarding improved yields, the latest innovation tested in Senegal was the use of beneficial indigenous microorganisms (BIMs), produced from litter from different non-cultivated sites. The soil microorganisms colonizing the litter in decomposition on natural areas were multiplied through a simple acid lactic fermentation before being used as a complex and locally-originated microbial inoculum on agricultural soils where soil biodiversity had been depleted by agricultural practices. For some of these BIMs, the tests confirmed a genuine biostimulant potential on plant production and plant vigour, as well as the potential for biocontrol of certain crop pests (aphids, cabbage moths and root-knot nematodes; see Figure 14.3). These effects may be due to the presence of useful microorganisms in the BIMs used as well as some metabolites produced by these complex microbial consortia (e.g., phytohormones, biocidal compounds), which must still be isolated, identified and quantified.

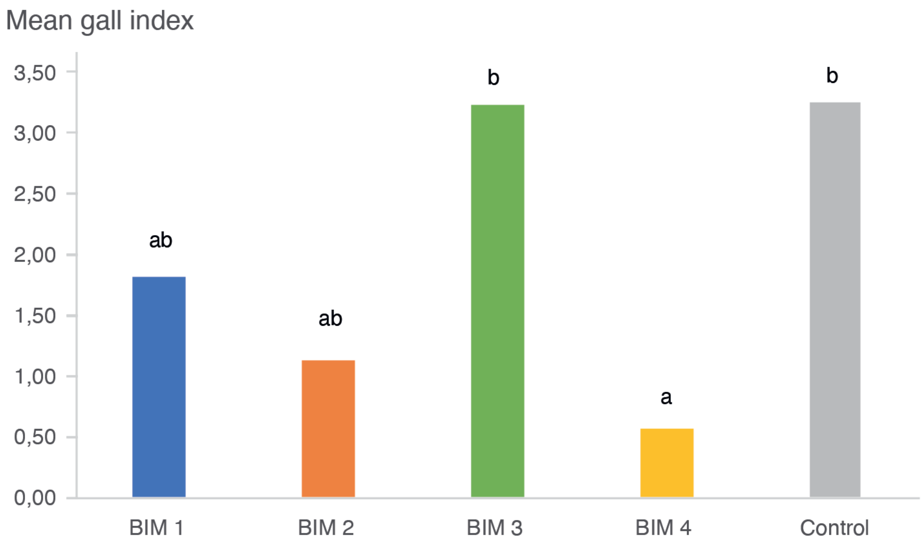

Figure 14.3. Effects of four beneficial indigenous microorganisms (BIMs)s originating from three different ecological regions of Senegal on root-knot gall index of lettuce when applied in farmers' market gardening fields near Baba Garage, Senegal.

Different letters indicate that there are significant differences ($P<0.05$) between the treatments (from Papa Samba Diagne, 2020, masterthesis, ISFAR). The higher the gall index, the higher the pressure of the root-knot gall nematode on the crop.

Institutional innovations

The development of market gardening and its support towards sustainable systems involve the deployment of technical as well as socio-economic and institutional policy measures.

To support producers in their agroecological transition, insect nets and adapted irrigation systems (small sprinkling or drip irrigation) are two key technical levers, but they represent considerable investments for family farms. In Tanzania, the investment in tunnels covered with insect nets is recovered only after about two years of production (i.e., after the sixth crop cycle), despite tunnels being manufactured at low cost from locally available materials (bamboo). This is due to the vegetables' low selling prices as well as consumers' inability to distinguish cabbages from each other based on health and visual quality criteria. Likewise, the use of local organic fertilizers is currently low due to the lack of knowledge of the actors in the sector, the low availability of raw materials to produce composts or organic fertilizers, and poor product competitiveness. The production costs of organic fertilizer are often greatly increased by transport costs of the raw materials to be recycled, which makes them more expensive compared to some imported or chemical fertilizers. Finally, local farmers often have little knowledge of biological inputs and biopesticides, and these products are often not readily available from agricultural input dealers.

In Madagascar, in the peri-urban area of Antananarivo, agroecological transition has been promoted by a project (ASA-EU) that encouraged organizational innovations at both the production and market levels. 'Leader' farmers were first trained and then tested agroecological production practices; after one or two crop seasons, each leader started training other farmers in their communities (David-Benz and Mino, 2018). These informal groups foster exchanges of experiences and mutual learning. To be able to sell their products in better conditions, each of these informal producers' groups coordinate with local collectors. On this basis, a participatory guarantee system was initiated. Such shifts, including changes in production practices and new institutional arrangements, are facilitated by the geographical proximity that characterizes peri-urban market gardening. But the learning process is long, adjustments are necessary from all sides, and farmers need sustained support.

The courses of action are therefore multiple and complementary. They can impact production through subsidies and subsidized loans to producers (to initiate investments such as micro-sprinkling irrigation), knowledge sharing and training (such as technical information sheets on fertilizer production). They can relate to upstream development of bioproduct production at the local level (subsidizing the transport costs of recycling raw materials) and rearing natural enemies, based especially on the enhancement of indigenous biodiversity (investment in action research). Finally, other actions can occur downstream through such initiatives as the establishment of participatory certifications to distinguish products on the market, consumer guarantees that production complies with food safety specifications, and increased selling prices. However, in low-income countries, these products are not affordable for most consumers and remain intended for limited niche markets. Without the emergence of a large middle class able to acquire these products at higher prices, widespread adoption of these modes of production would require policy measures to reduce production costs rather than increase selling prices.

Conclusion

Market vegetable gardening is developing in the peri-urban (suburban) areas of African cities to meet growing consumer demand. Thanks to the adaptability of farmers, market gardening systems are very flexible and do well in both urban and peri-urban areas. The challenge is to support their development so that they are more sustainable from social, economic and environmental points of view (e.g., Temple and De Bon, 2020). Achieving this implies technical and institutional innovations at three levels. At the production level, support policies are needed to accompany producers in the use of technologies, strategies and materials that save water, protect biodiversity and recycle organic residues. At the sectoral level, public actions are needed to stimulate the development of new services (rearing of natural enemies, transport of organic materials to be recycled), to recognize and promote the implementation of product differentiation such as through participatory guarantee systems, and to raise consumer awareness regarding sustainable, environmentally-friendly production practices. At the local and regional levels, commitments from decision-makers are needed to ensure land-use planning that accounts for the coexistence of agriculture and the built environment, and to secure land rights and access to water for producers in increasingly competitive areas.

⏩ Acknowledgements

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Conclusion
GloFoodS: an actor and marker of deep transformations in the international agenda

Patrick Caron, Marion Guillou

As INRAE and CIRAD were implementing the GloFoodS interdisciplinary programme in 2014, the international agenda was being completely transformed over the same period. Food security, which was formally set out as a key global priority at the World Food Conference in 1974, was gradually ceding its place to sustainable food systems. At a time of dizzying demographic growth in the second half of the 20th century, the emphasis on increasing supply and organising trade while stabilising prices was accompanied by growing criticism and calls for profound changes in ways of thinking and acting. Thus, MacIntyre et al. (2009) put the focus on learning systems, and Beddington et al. (2011) called on research stakeholders to address the challenge of climate change by modifying food systems. The concomitance of these two movements reflects a dual reality. First, scientific communities actively contribute to the evolution of international agendas, and second, they also are deeply impacted by such shifts. The GloFoodS programme thus appears to be an excellent marker of this global shift. While the projects funded by GloFoodS are concentrated in the area of food security, we can still clearly see the emergence of the food system concept.

From the beginning of the early 2000s, the world became more aware that food systems are an integral part of the complex and intersectoral issues of sustainability for the planet and humanity. The awarding of the 2007 Nobel Peace Prize to the IPCC highlighted the importance of climate change, and the call by IPCC chair Rajendra Pachauri to stop eating meat reaffirmed the significance of the issue. With the earthquake, and after a so-called hunger riot in 2008, global leaders put the issue of food back at the top of the international agenda. The aim is no longer to just produce more – a legitimate 20th-century priority – but to reposition food as we build our future world (Caron et al., 2018). These ideas were enshrined in the UN's Global Sustainable Development Report in 2019.

We can identify at least five major changes, which GloFoodS reported on. These changes did not suddenly appear as the food system concept gained traction. Rather, the research community prepared and developed them, along with the critical reflections that marked its own orientation, management and programming over the last decades. One of the major ambitions of research is thus affirmed: to produce knowledge that can help think and structure action.

The first of these five major changes concerns technical progress. Alone, it is no longer sufficient to address societal questions and meet the challenges facing institutions. Technical progress, productivity, production, increased income and food security no longer go hand in hand, as illustrated by the Sikasso Paradox (Dury and Bocoum, 2012). This is the case in all regions and countries, and not only in Mali. Any technique that increases crop yield is not systematically profitable or adopted by farmers (Sebillotte, 1996), as was previously the case. Technological performance and the relevance of technical change must now address much more complex questions, especially since they vary from place to place. Beyond the immediate crop yield, production system resilience (Bousquet et al., 2014) – particularly in the event of disruptive climatic conditions, hazards of all kinds and price uncertainties – becomes essential if actors are to implement new techniques. In this context, agricultural research institutions are increasingly looking to the human and social sciences (Goulet et al., 2022) and system-based approaches, which emerged in the 1980s to investigate innovation processes and support producers' behaviours and decision-making. The increasing attention paid to the institutional dimension of the innovation ecosystem (Coudel et al., 2012) reflects the issues associated with the conditions, modalities and consequences of technical change. The resulting tensions and crises, such as those surrounding genetically modified organisms (GMOs), mad cow disease, or glyphosate, mean that dealing with socio-technical controversies (Latour, 1987) is now a new major challenge.

A second change has resulted from a desire from some academics to overcome a dominant and prescriptive attitude from science and a view to limit its mission to inventing technologies for transfer. Echoing the first major change about technical progress, research teams are now interested in the design of innovation and the devices that enable it. Researchers engage in participatory science practices, working to strengthen their capacity to reflect upon the stated and promoted impact on an individual, collective and institutional basis. The development of a culture of innovation and impact is embodied in institutional initiatives such as the Socio-Economic Analysis of the Impacts of Public Agricultural Research (ASIRPA) and Impact of Research in the South (IMPRESS).

The third change follows on from the above aims: ensuring food security, tackling the challenges of sustainable development, and guaranteeing decent and fair living conditions for those in the agricultural and food sectors. Achieving these aims will require doing more than focusing on agricultural production alone, and this applies to agricultural research institutions as well. This has been emphasized by the World Development Report 2008 by the World Bank (2007) but was already an issue of concern. The development of sector approaches, from the 1970s, seemed to mark the start of a new era. Research activities began to look beyond the food supply, to focus on food environments and consumer behaviours. For example, INRA created a new Department of Consumer Sciences in 1979. All these issues have been recognised more recently as essential pillars of food systems at the international level.

Similarly, agricultural research institutions began acknowledging the importance of work on environmental topics, propelled by the emergence of such issues in the 1970s. INRA added them to its research priorities in the 1990s, and their importance was further recognised in the international agenda with the creation in 1993 and 1994 of the three environmental conventions regarding climate (UNFCCC), biodiversity (UNCBD) and desertification (UNCCD) engagements. In the 2000s, the notion of nexus gradually came to the fore, in order to address the complex interactions between these different sectors. Similar shifts could also be seen in CIRAD's research agenda.

The fourth shift within our research institutions has been the strengthening of ties between INRA and CIRAD. This relied on the de-compartmentalizing between temperate and tropical spheres, maintained among other things by the previous justification of references to distinct commodities and value chains. This is consistent with heralding the erasure of north-south segmentations in the 2030 Agenda for sustainable development. This evolution has enriched the activities of each organization and allowed the analysis of global issues – whether environmental, climate-, health- or trade-related. The convergences between our institutions have been strengthened, as shown by GlofoodS. Scientific discussions and projects within joint research units have cultivated fruitful comparisons and, as a consequence, decentrations in scientific reasoning. They have helped to reposition each institute's activities and approaches by enhancing their specificities and taking into account international contexts and issues through scientific and development partnerships. This process of strengthening relations between INRA and CIRAD was not a straightforward one, and it was proactively encouraged through initiatives such as Agrimonde (launched in 2006) and Dualine (launched in 2009) before doing so through jointly sponsored research programmes such as GloFoodS.

Fifth, the growing importance of globale issues in our field and the widening of INRAE geographic mandate have fueled INRAE and CIRAD ambition to position their scientific advances in the world and to influence international thinking, as was explicitly expressed in CIRAD's strategy in 2014. The recognition of their contributions to the international agenda is not obvious. Louis Malassis's definition of food systems from 1994 is for example still overlooked despite insistence, even as the concept of food systems, now in vogue, is most often attributed to Ingram (2011); no matter its sustainability has been the center of DuALIne research program launched in November 2009 by INRA and Cirad. The same is true of the concept of multifunctionality, first defined in the 1990s, rejected by export countries because of the suspicions of distortion of international trade to which it would give rise, and which is now emerging again. However, some methods or approaches have been widely recognized as the affirmation of forward-looking reasoning via the conduct of Agrimonde foresight study or the exploration of possible futures of the world's agricultural and food systems up to 2050. Opening ourselves to the world implies to work together to join international programmes and initiatives and to make INRAE and CIRAD voices heard with our partners in these instances. This was undertaken on the occasions of our participation in the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) and the Global Conferences on Agricultural Research for Development (GCARD) as well as our involvement in the CGIAR global research partnership, Global Forum on Agricultural Research (GFAR) and the High Level Panel of Experts on Food Security and Nutrition (HLPE of the United Nations Committee on World Food Security – CSA). Such international experiences provide opportunities to better connect what is happening locally, nationally and globally.

Finally, in a context where negative externalities are attributed to globalisation, there is now a keen interest for all things 'local', and the pioneering work to re-territorialise agriculture attests to this. With the return of the concept of local or national food sovereignty, spurred by the Covid pandemic, we must avoid the trap of localism and strict confinement within national borders. We must not just 'think global, act local' but rather think and act *both* locally and globally in a coherent way. The interdisciplinary and interinstitutional GloFoodS programme showed that it was possible to do so, and thus offered a way to escape the pitfalls associated with scaling up, where by solutions that were designed and used in one place would simply be replicated elsewhere. With the United Nations Food Systems Summit 2021, an ambitious international agenda for the years to come and a renewed commitment to multilateralism after a several-year hiatus, it is up to us to make the most of these opportunities.

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Food and nutritional security refers to the challenge of providing sustainable, healthy and accessible food to all people. It has four interconnected dimensions: availability, access, utilization and stability. Tackling this tremendous challenge means transforming our food systems and mobilizing key stakeholders and decision-makers to leverage intersectoral knowledge and scientific evidence. From 2014 to 2020, CIRAD and INRAE led an ambitious interdisciplinary flagship programme on the transitions for global food security called GloFoodS.

Authored by principal investigators and contributors to research projects funded by GloFoodS, this book is representative of the programme's interdisciplinary research but does not claim to provide exhaustive coverage of topics and approaches of food security. It presents recent research findings from many disciplines, including the life, engineering and social sciences. The findings were drawn from different analysis scales as well as from the combination of local and global food security approaches. The various chapters explore issues such as food system governance, balance and discrepancies between agricultural supply and food needs, the role of innovations in providing high-quality foods and promoting resilient value chains, and the role of local resource management in achieving food security.

This book will be of interest to a broad scientific audience of researchers, academics, food systems professionals and decision-makers, as well as readers interested in food and nutritional security issues.

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