Crop diversity in a changing world: evidence from Bassari farmers in south-eastern Senegal

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Directed by:
Dr. Victoria Reyes-García Dr. Vanesse Labeyrie Dr. Ndèye Fatou Faye

PhD Programme in Environmental Science and Technology
Institut de Ciència i Tecnologia Ambientals, ICTA
Universitat Autònoma de Barcelona, UAB

In collaboration with:
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ISRA-BAME, Bureau d'Analyses Macro-économiques,
Institut Sénégalais de Recherches Agricoles, Dakar, Senegal

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Affiliations of PhD supervisors:
Dr. Victoria Reyes-García
Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona (ICTA-UAB), Barcelona, Spain
ICREA, Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain
Departament d'Antropologia Social i Cultural, Universitat Autònoma de Barcelona, Barcelona, Spain
Dr. Vanesse Labeyrie
SENS, Université de Montpellier, CIRAD, IRD, UPVM, Montpellier, France
CIRAD, UMR SENS, F-34398, Montpellier, France
Dr. Ndèye Fatou Faye
Institut Sénégalais de Recherches Agricoles, Pôle de Recherche de Hann, route du front de terre, Dakar, Sénégal

Academic tutor: **Dr. Victoria Reyes-García**

Cover design: Eva Porcuna Ferrer
Pre-chapter covers: Eva Porcuna Ferrer (drawings), Anna Porcuna Ferrer (text)
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Summary

Crop diversity is important for building resilient farming systems. While the need to support and enhance diversity in farmers' fields is widely acknowledged, the complex context in which farmers manoeuvre does not always allow them to maintain crop diversity in general, or to prioritize the maintenance of climate-adapted crop portfolios in particular. This thesis aims to help understand the processes driving local crop diversity dynamics in a context of climate change. Qualitative and quantitative data were collected over 16 months among the Bassari of south-eastern Senegal.

Chapters three and four describe the context in which Bassari farmers make decisions. Climate change is framed from a relational perspective, connecting its impacts with cross-scale dynamics affecting communities and their farming practices. To this end semi-structured interviews (n=47), focus group discussions (n=3), and household surveys (n=176) were carried out. The results show that Bassari farmers work within highly variable and interacting climatic, environmental, and political conditions. Although they are concerned about increasing climatic variability, climate change is not the main factor driving farmers' agricultural decisions. Economic and socio-cultural factors play a more important role. The findings also show that changes in agricultural practices entail diverse costs, benefits, and trade-offs for different social groups, with the most vulnerable bearing most of the costs.

Chapter five provides a longitudinal cross-scale perspective on local crop diversity dynamics, exploring how global-change processes intersect with household-level dynamics to shape farmers' decision-making regarding which crops to grow. It combines secondary data obtained through archival research with primary data (n=47 semi-structured interviews, n=49 household surveys). My results show that traditional staple crop species and varieties with adaptive potential to drought are being abandoned. The reasons for their abandonment are linked to both broad-scale dynamics and household-level factors. Market forces, agricultural policies, official seed production and distribution channels, and historical legacies intersect with shifting gender roles, labour relations, and dietary changes, leading to the switch from traditional drought-tolerant crops to introduced water-demanding crops.

Chapter six uses social network analysis to explore contemporary processes driving farmers' access to and cultivation of diverse crop portfolios. Crop diversity inventories and household surveys on seed acquisitions (n=117 households) were conducted for the six main local staple crops. The results suggest that the processes and mechanisms driving farmers' access to seeds depend, at least partly, on a crops' biocultural status. Traditional crops circulate in somewhat restricted ways whereas introduced crops circulate in less restricted but more centralized ways. The findings also show that farmers who play a more central role in the network of seed exchange conserve more diversity than farmers who play a less central role.

This thesis sheds light on the processes driving local crop diversity dynamics, illustrating the complexity of social, cultural, and environmental transformations affecting smallholder farming systems. The findings highlight the multiple trade-offs in crop diversity in response to different drivers, contributing to the discussion about how the resilience of an agroecosystem can be increased or diminished. While farmers' contemporary choices often respond to short-term drivers, these choices can compromise long-term resilience to climate change. My thesis emphasizes the importance of understanding crops as biocultural elements with complex material and immaterial dimensions, and examining them from a longitudinal cross-scale perspective and considering power dynamics.

In the conclusion, I argue that to promote change towards more resilient agricultural systems, there is a need to move beyond narratives addressing climate change as the sole or main cause of challenges in smallholder farming systems. It is also essential to move beyond research and development focused on a handful of crops and centralized hierarchic seed and knowledge diffusion systems towards collaborative and community-engaged research that places farmers at the centre.

Key words: agrobiodiversity, biocultural diversity, climate change, farmers' decision-making, local knowledge, resilience, seed systems, Senegal, small-scale farming

Résumé

La diversité cultivée joue un rôle central dans la résilience des systèmes agricoles. Bien que la nécessité de favoriser la diversité des cultures soit largement reconnue, le contexte complexe dans lequel évoluent les agriculteurs et agricultrices* ne leur permet pas toujours de mantenir une diversité des cultures en général, ni de donner la priorité au maintien de paniers de cultures adaptées au changement climatique en particulier. Cette thèse vise à mieux comprendre les processus qui influencent les dynamiques locales de la diversité cultivée dans un contexte de changement climatique. Elle se base pour cela sur des données qualitatives et quantitatives collectées sur une période de 16 mois chez les Bassari du sud-est du Sénégal.

Les chapitres trois et quatre décrivent le contexte dans lequel les agriculteurs Bassari prennent des décisions concernant le choix de leurs cultures. J'aborde le changement climatique d'une perspective relationnelle, en reliant ses impacts aux autres facteurs de changement affectant les communautés et leurs pratiques agricoles. J'ai mené des entretiens semi-structurés (n=47), des discussions de groupe (n=3) et des enquêtes à partir de questionnaires auprès des ménages (n=176). Les résultats montrent que les agriculteurs Bassari évoluent dans des conditions climatiques, environnementales et politiques très variables et interdépendantes. Bien qu'ils soient préoccupés par l'augmentation de la variabilité climatique, le changement climatique n'est pas le principal facteur qui influence les décisions des agriculteurs concernant le choix de leurs cultures. Les facteurs économiques et socioculturels jouent un rôle plus important. Les résultats montrent également que les changements dans les pratiques agricoles entraînent des coûts, des bénéfices et des compromis différents selon les groupes sociaux, les plus vulnérables supportant la plupart des coûts.

Le chapitre cinq offre une perspective longitudinale et transversale sur les dynamiques locales de la diversité des cultures. Il explore comment les facteurs de changement globaux interagissent avec les dynamiques au niveau des ménages pour influencer les décisions des agriculteurs concernant les paniers d'espèces cultivées. Il combine une analyse de la littérature concernant l'histoire de la zone d'étude et du développement agricole au Sénégal avec des données d'enquêtes (n=47 entretiens semi-structurés, n=49 enquêtes auprès des ménages). Les résultats montrent que les espèces vivrières cultivées anciennement dans la zone d'étude et les variétés présentant des caractéristiques d'adaptation à la sécheresse sont abandonnées. Les raisons de leur abandon sont liées à la fois aux facteurs de changement à l'échelle globale et nationale, et aux dynamiques à l'échelle des ménages. Les forces du marché, les politiques agricoles, les canaux officiels de production et de distribution des semences, ainsi que les héritages historiques interagissent avec

* Le masculin générique est utilisé pour faciliter la lecture, mais, «agriculteurs» fait référence aux «agriculteurs et agricultrices».

l'évolution des rôles de genre, des relations de travail et des changements alimentaires, conduisant au remplacement des cultures traditionnelles tolérantes à la sécheresse par des cultures introduites exigeant plus d'eau.

Le chapitre six utilise l'analyse des réseaux sociaux pour explorer les processus contemporains qui déterminent l'accès des agriculteurs à la diversité cultivée. Cette analyse se base sur des inventaires de diversité des espèces et variétés cultivées et des enquêtes auprès des ménages concernant les acquisitions de semences (n = 117 ménages) pour les six principales cultures vivrières locales. Les résultats soulignent que les processus qui régissent l'accès des agriculteurs aux semences dépendent, du moins en partie, du statut bioculturel de chaque espèce au sein de la communauté. Les espèces anciennement cultivées dans la zone circulent de manière plus restreinte et moins centralisée que celles qui ont été introduites. Les résultats montrent également que les agriculteurs occupant une place plus centrale dans le réseau d'échange de semences conservent une plus grande diversité variétale que ceux occupant une place moins centrale.

Cette thèse éclaire les processus qui influencent les dynamiques locales de la diversité cultivée, illustrant la complexité des transformations sociales, culturelles et environnementales affectant les systèmes agricoles familiaux diversifiés. Ces résultats mettent en évidence les multiples compromis relatifs à la diversité cultivée mise en œuvre par les agriculteurs en réponse à différents moteurs. Ils montrent que les choix contemporains des agriculteurs répondent souvent à des moteurs à court terme, et peuvent compromettre la résilience des systèmes agricoles à long terme face au changement climatique. Ma thèse souligne l'importance de considérer les plantes cultivées comme des éléments bioculturels, couvrant des dimensions matérielles et immatérielles complexes, et de les examiner dans une perspective diachronique.

En conclusion, ma thèse souligne la nécessité de dépasser les récits mettant en avant le changement climatique comme le principal défi pour les systèmes agricoles familiaux en Afrique, afin de promouvoir des systèmes agricoles plus résilients. Elle montre également l'importance de développer des approches de recherche et de développement prenant en compte la diversité des cultures au sein des systèmes agricoles et d'avancer vers davantage de décentralisation des systèmes de diffusion des semences et des connaissances, au profit d'une recherche collaborative et engagée auprès des communautés, plaçant les agriculteurs.ices au centre.

Mots-clés: agrobiodiversité, diversité bioculturelle, changement climatique, prise de décision des agriculteurs.ices, connaissance locale, résilience, systèmes semenciers, Sénégal, agriculture familiale

Resumen

La agrobiodiversidad es importante para crear sistemas agrícolas resilientes. Aunque la necesidad de apoyar y potenciar la agrobiodiversidad está ampliamente reconocida, el complejo contexto en el que se mueven los agricultores y las agricultoras* no siempre les permite mantener una diversidad de cultivos en general o priorizar el mantenimiento de carteras de cultivos adaptadas al clima en particular. Esta tesis propone ahondar en los procesos que impulsan las dinámicas en la diversidad de cultivos locales en un contexto de cambio climático. Para ello se recopilaron datos cualitativos y cuantitativos entre los Bassari del sudeste de Senegal durante 16 meses.

Los capítulos tres y cuatro describen el contexto en el que los agricultores Bassari toman decisiones. Se enmarca el cambio climático desde una perspectiva relacional, conectando sus repercusiones con dinámicas entre escalas que afectan a las comunidades y sus prácticas agrícolas. Tras la realización de entrevistas semiestructuradas (n=47), debates en grupos focales (n=3) y encuestas en hogares (n=176), los resultados muestran que los agricultores Bassari trabajan en condiciones climáticas, medioambientales y políticas muy variables que interactúan entre sí. Aunque les preocupa la creciente variabilidad climática, el cambio climático no es el principal factor que impulsa sus decisiones agrícolas. Los factores económicos y socioculturales juegan un papel más importante. Los resultados también muestran que los cambios en las prácticas agrícolas conllevan diversos costes, beneficios y compensaciones para los distintos grupos sociales, y que los más vulnerables soportan la mayor parte de los costes.

El capítulo cinco ofrece una perspectiva longitudinal de la dinámica local de la diversidad de cultivos a escala regional, nacional y local, explorando cómo los procesos de cambio global se entrecruzan con dinámicas domésticas que configuran la toma de decisiones de los agricultores en la elección de cultivos. Tras combinar datos secundarios obtenidos mediante investigación de archivo con datos primarios (n=47 entrevistas semiestructuradas, n=49 encuestas a hogares), los resultados muestran que se están abandonando las especies y variedades de cultivos básicos tradicionales con potencial de adaptación a la sequía. Las razones de su abandono están vinculadas tanto a dinámicas a gran escala como a factores relativos al hogar. Las fuerzas del mercado, las políticas agrícolas, los canales oficiales de producción y distribución de semillas y los legados históricos se entrecruzan con los cambios en los roles de género, las relaciones laborales y los cambios en la dieta, lo que conduce a la sustitución de cultivos tradicionales tolerantes a la sequía por cultivos introducidos que requieren más agua.

* Se utiliza el masculino genérico para facilitar la lectura, pero “agricultores” hace referencia a “agricultores y agricultoras”.

El capítulo seis utiliza análisis de redes sociales para explorar los procesos contemporáneos que impulsan el acceso de los agricultores a diversas carteras de cultivos. Tras realizar inventarios de diversidad de cultivos y encuestas a hogares sobre la adquisición de semillas (n = 117 hogares) de los seis principales cultivos básicos locales, los resultados sugieren que los procesos y mecanismos que impulsan el acceso de los agricultores a las semillas dependen -al menos en parte- del estatus biocultural que el cultivo tiene en la comunidad. Los cultivos tradicionales circulan de forma restringida, mientras que los introducidos lo hacen de forma menos restringida pero más centralizada. Los resultados también muestran que los agricultores que desempeñan un papel más central en la red de intercambio de semillas conservan más diversidad que aquellos que desempeñan un papel menos central.

Esta tesis profundiza sobre los procesos que impulsan cambios en la diversidad de cultivos locales, al ilustrar la complejidad de las transformaciones sociales, culturales y medioambientales que afectan a los sistemas agrícolas de los pequeños agricultores. Las conclusiones ponen de relieve los múltiples compromisos que se producen en la diversidad de cultivos en respuesta a distintos factores responsables de esta diversidad. Esto contribuye a los debates sobre cómo apoyar la resiliencia de los agroecosistemas de pequeños agricultores. Aunque las decisiones de los agricultores responden a menudo a factores a corto plazo, estas decisiones pueden comprometer la resiliencia del agroecosistema al cambio climático a largo plazo. La tesis subraya la importancia de entender los cultivos como elementos bioculturales, con complejas dimensiones materiales e inmateriales, y la necesidad de examinarlos considerando las dinámicas de poder y desde una perspectiva diacrónica.

En conclusión, se sostiene que para promover el cambio hacia sistemas agrícolas más resilientes, es necesario ir más allá de las narrativas que abordan el cambio climático como la única o principal causa de los desafíos en los sistemas agrícolas de los pequeños agricultores. También que es esencial ir más allá de la investigación y el desarrollo centrados en número limitado de cultivos y basados en sistemas de difusión de semillas y conocimientos jerárquicos y centralizados, para tender hacia una investigación colaborativa y comprometida con la comunidad que sitúe a los agricultores en el centro.

Palabras clave: agrobiodiversidad, diversidad biocultural, cambio climático, toma de decisiones de los agricultores, conocimiento local, resiliencia, sistemas de semillas, Senegal, agricultura a pequeña escala

Resum

L'agrobiodiversitat és important per a crear sistemes agrícoles resilients. Encara que la necessitat de secundar i potenciar l'agrobiodiversitat està àmpliament reconeguda, el complex context en el qual es mouen els agricultors i les agricultores* no sempre els permet mantenir una diversitat de cultius ni prioritzar el manteniment de carteres de cultius adaptades al clima. Aquesta tesi proposa aprofundir en els processos que impulsen les dinàmiques locals en la diversitat de cultius en un context de canvi climàtic. Per a això es van recopilar dades qualitatives i quantitatives entre els Bassari del sud-est del Senegal durant 16 mesos.

Els capítols tres i quatre descriuen el context en el qual els agricultors Bassari prenen decisions. S'emmarca el canvi climàtic des d'una perspectiva relacional, connectant les seves repercussions amb dinàmiques entre escales que afecten les comunitats i les seves pràctiques agrícoles. Després de la realització d'entrevistes semiestructurades (n = 47), debats en grups focals (n = 3) i enquestes a llars (n = 176), els resultats mostren que els agricultors Bassari treballen en condicions climàtiques, mediambientals i polítiques molt variables que interactuen entre si. Encara que els preocupa la creixent variabilitat climàtica, el canvi climàtic no és el principal factor que impulsa les seves decisions agrícoles. Els factors econòmics i socioculturals juguen un paper més important. Els resultats també mostren que els canvis en les pràctiques agrícoles comporten diversos costos, beneficis i compensacions per als diferents grups socials, i que els més vulnerables afronten la major part dels costos.

El capítol cinc ofereix una perspectiva longitudinal de la dinàmica local de la diversitat de cultius a escala regional, nacional i local, i explora com els processos de canvi global s'entrecreuen amb dinàmiques domèstiques que configuren l'elecció de cultius per part dels agricultors. Després de combinar dades secundàries obtingudes mitjançant recerca d'arxiu amb dades primàries (n = 47 entrevistes semiestructurades, n = 49 enquestes a llars), els resultats mostren que s'estan abandonant les espècies i varietats de cultius bàsics tradicionals amb potencial d'adaptació a la sequera. Les raons del seu abandó estan vinculades tant a dinàmiques a gran escala com a factors relatius a la llar. Les forces del mercat, les polítiques agrícoles, els canals oficials de producció i distribució de llavors i els llegats històrics s'entrecreuen amb els canvis en els rols de gènere, les relacions laborals i els canvis en la dieta, la qual cosa condueix a la substitució de cultius tradicionals tolerants a la sequera per cultius introduïts que requereixen més aigua.

* S'utilitza el masculí genèric per facilitar la lectura, però en tot el text "agricultors" fa referencia a "agricultors i agricultores".

El capítol sis utilitza una anàlisi de xarxes socials per a explorar els processos contemporanis que impulsen l'accés dels agricultors a diverses carteres de cultius i ús. Després de realitzar inventaris de diversitat de cultius i enquestes a llars sobre l'adquisició de llavors dels sis principals cultius bàsics locals (n = 117 llars), els resultats suggereixen que els processos i mecanismes que impulsen l'accés dels agricultors a les llavors depenen –almenys en part– de l'estatus biocultural que el cultiu té en la comunitat. Els cultius tradicionals circulen de forma restringida, mentre que els introduïts ho fan de forma menys restringida però més centralitzada. Els resultats també mostren que els agricultors que exerceixen un paper més central en la xarxa d'intercanvi de llavors conserven més diversitat que aquells que exerceixen un paper menys central.

Aquesta tesis aprofundeix, d'una banda, sobre els processos que impulsen la dinàmica en la diversitat dels cultius locals, i de l'altra, en la complexitat de les transformacions socials, culturals i mediambientals que afecten els sistemes agrícoles dels petits agricultors. Les conclusions posen en relleu els múltiples compromisos que afecten les eleccions i les pràctiques dels agricultors pel que fa a la diversitat de cultius. Això contribueix als debats sobre com donar suport a la resiliència dels agroecosistemes de petits agricultors. Encara que les decisions dels agricultors responen sovint a factors a curt termini, aquestes decisions poden comprometre la resiliència de l'agroecosistema al canvi climàtic a llarg termini. La tesi subratlla la importància d'entendre els cultius com a elements bioculturals, amb dimensions materials i immaterials complexes, i la necessitat d'examinar-los tenint en compte les dinàmiques de poder i des d'una perspectiva diacrònica.

Com a conclusió, se sosté que, per a promoure el canvi cap a sistemes agrícoles més resilients, és necessari anar més enllà de les narratives que aborden el canvi climàtic com l'única o principal causa dels desafiaments en els sistemes agrícoles dels petits agricultors. També defensa que és essencial anar més enllà de la recerca i el desenvolupament centrats en nombre limitat de cultius i basats en sistemes de difusió de llavors i coneixements jeràrquics i centralitzats, per a tendir cap a una recerca col·laborativa i compromesa amb la comunitat que situï els agricultors al centre.

Paraules clau: agrobiodiversitat, diversitat biocultural, canvi climàtic, presa de decisions dels agricultors, coneixement local, resiliència, sistemes de llavors, Senegal, agricultura a petita escala

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Main acronyms and abbreviations

ANACIM:	National Agency for Civil Aviation and Meteorology (‘Agence Nationale de l’Aviation Civile et de la Météorologie’)
ARD :	Regional Development Agency (‘Agence Régionale de Développement’)
CIRAD:	French Agricultural Research Centre for International Development
DAPSA :	Directorate of Analysis, Forecasting and Agricultural Statistics (‘Direction de l’Analyse, de la Prévision et des Statistiques Agricoles’)
DPN :	Direction of National Parks (‘Direction Des Parcs Nationaux’)
FAO:	Food and Agriculture Organization
GIE :	Group of economic interest (‘Groupement d’intérêt économique’)
GOANA :	Grand Agricultural Offensive for Food and Abundance (‘Grande Offensive Agricole pour la Nourriture et l’Abondance’)
ILK:	Indigenous and local knowledge
IPCC:	Intergovernmental Panel on Climate Change
IPBES:	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ISRA:	Senegalese Institute of Agricultural Research (‘Institute Sénégalaise de Recherches Agricoles’)
LICCI:	Local indicator of climate change impact
LICCI-Project:	ERC research project entitled “Local indicators of climate change impacts. The contribution of local knowledge to climate change research” (https://licci.eu)
NGO:	Non-governmental organization
NPA:	New agricultural policy (‘Nouvelle Politique Agricole’)
NUS:	Neglected and underutilized species
PA:	Agricultural program (‘Programme Agricole’)
PAML:	Medium and long-term economic and financial adjustment plan (‘Plan d’ajustement économique et financier à moyen et long terme’)
PDDAA:	Detailed program for the development of agriculture in Africa (‘Programme Détaillé du Développement de l’Agriculture en Afrique’)
PNAR:	National rice self-sufficiency program (‘Programme National d’Autosuffisance en Riz’)
PRACAS:	Program for accelerated pace of agriculture (‘Programme d’Acceleration de la Cadence de l’Agriculture Senegalaise’)
PREF:	Economic and financial recovery plan (‘Plan de Redressement Économique et Financier’)
PSE:	Plan for an emerging Senegal (‘Plan Senegal Emergent’)
REVA:	Plan to return to agriculture (‘Plan Retour vers l’Agriculture’)
SAP:	Structural adjustment program
SSI:	Semi-structured interviews
SNA:	Social network analysis
SODEFITEX:	Senegalese Textile Fibres and Development Company (‘Société de Développement et des Fibres Textiles’)
UAB:	Autonomous University of Barcelona
UNESCO:	United Nations Educational Scientific and Cultural Organization

Preface

Over the centuries, Bassari have developed a deep knowledge of the plants, the soils, and the climate in their environment. To capture this knowledge, one must take the time to learn from those who have lived and worked this land for generations. Only when you learn to look at the landscape slowly …amid the sweet-sour smell of fermenting sorghum beer, to the rhythm of the pestle, to the sound of the hoe digging the dry earth, to the crack of peanuts being dehusked… only then can you perceive what is invisible to the gaze. The crops growing in the fields are not simply food, cash, fodder, or medicine. They are also a link to the past, to the ancestors, and to promises for a better life. The mosaic of bush and fields mirrors generations of farmers working this land together, tending these crops, a culture which has created a uniquely diverse crop landscape.

This dissertation studies the shaping of crop diversity in south-eastern Senegal. It is the result of a four-year PhD project based at the Institut de Ciència i Tecnologia Ambientals of the Autonomous University of Barcelona (ICTA-UAB) in Spain, in collaboration with the Bureau d'Analyses Macroéconomiques of the Institute Sénégalais de Recherches Agricoles (ISRA-BAME) in Senegal, and the research group Savoirs, Environnement et Sociétés of the French Agricultural Research Centre for International Development (UMR SENS, CIRAD) in France. The research took place within the framework of a larger research project –Local Indicators of Climate Change Impacts (LICCI-ERC)– that draws on Indigenous and local knowledge to understand situated notions of climate change impacts and adaptation actions. It included 16 months of fieldwork in the Bassari territory, south-eastern Senegal, and a four-month stay at the UMR SENS in CIRAD, Montpellier, France.

The thesis has seven chapters: two introductory chapters, four empirical chapters, and a conclusion. Three of the empirical chapters correspond to manuscripts published in scientific journals and one corresponds to a published book chapter.

Chapter 1
Introduction

Delayed *Ge-tyasya* (time to seed)

The landscape is dull brown, dry, and scattered with bushes, burned fields, mango trees, and baobabs.

In the past, the rainy season started earlier, I was told; by this time, the first sorghum seeds would have begun germinating across the fields and seasonal rivers would be flowing with the first waters. But it is early June, many fields are not yet ploughed and the riverbeds are dry.

The rainy season has now shortened from about six months to four months, and the dry-spells have become more frequent and less predictable.

Introduction

The global food system is in crisis. Not only has it failed to achieve global food and nutrition security for the world's population (FAO et al., 2023; Willett et al., 2019) but it exacerbates inequalities and environmental unsustainability (Akram-Lodhi, 2014; Evans et al., 2019; IPBES, 2019). An added dimension to the already existing challenges in the global food system is climate change (IPCC, 2023). A global temperature rise above pre-industrial levels could lead to dramatic reductions in crop yields (Roudier et al., 2011; Challinor et al., 2014). Such shifts imply the urgent need to adapt and build more resilient farming systems.

To date, the development and expansion of industrial agriculture has been the mainstream approach to achieve global food security. Many experts, however, argue that continuing with agricultural development focused on an homogeneous and intensified agricultural production oriented towards commodity markets will only increase environmental impacts and further aggravate wealth, social, and environmental inequalities (Khoury et al., 2014; IPBES-Food, 2016). In this context, the pursuit of farming systems that respect environmental limits while simultaneously addressing food security and climate resilience has become a major goal among researchers, farmers and policymakers worldwide.

Diversified agroecological farming systems appear to be a promising alternative to industrial forms of farming (Altieri et al., 2012; Gliessman, 2014; Kerr, 2020). One key characteristic of these systems is the reliance on crop diversity. Crop diversity performs an important role by providing ecosystem services that extend beyond food, fibre, fuel, and income, and include the fulfilment of important ecological and cultural functions (Altieri, 1999a; Howard, 2010). By reconciling environmental and socio-economic concerns, crop diversity-based farming systems could provide a better support both for people and nature. Farming systems with high levels of crop diversity not only require less external input and help satisfy the multiple needs of local communities but are also more resilient to both environmental and socio-economic perturbations (Lin, 2011; Isbell et al., 2017; Renard and Tilman, 2019).

Worldwide crop diversity is concentrated and deeply embedded in the farming systems of smallholder farming communities in the Global South. Smallholder farmers have traditionally developed and maintained a wide diversity of crops and landraces (Brush, 1995; Jarvis et al., 2008; Zimmerer and Haan, 2017). Nevertheless, in recent decades, the crop base in fields and kitchens has become increasingly narrow (Khoury et al., 2014). The homogenization of crop diversity raises concerns for the resilience of smallholder farmers in the face of increasing climatic uncertainty (Lin, 2011). Smallholder farming systems are predicted to be especially hard hit by the impacts of climate change since they mostly depend on rainfall and lack the financial or institutional mechanisms to respond and adapt to climate shocks and impacts (Morton, 2007; Sultan et al., 2020).

Although crop diversity has historically served as a buffer against the effects of climate variability in smallholder farming systems, recent research suggests that the uptake of broader diversification approaches is slow despite the intensifying effects of climate change (Labeyrie et al., 2021b). One of the key questions is: what are the trade-offs of maintaining high levels of crop diversity? The benefits

of crop diversity are widely acknowledged but less is known about the interplay between cross-scale biophysical and social dynamics, and crop diversity shifts at the local scale. The complex contexts in which smallholder farmers manoeuvre do not always allow them to prioritize the maintenance of diverse and climate-adapted crop portfolios. To support smallholder farmers to maintain and enhance crop diversity in their fields, a better understanding of crop diversity dynamics seems crucial.

This dissertation examines how the interweaving of socio-cultural and ecological transformations affects crop diversity dynamics and climate resilience. To address this question, the thesis builds on a compilation of in-depth, qualitative and quantitative social-ecological data collected over a period of 16 months among the Bassari of south-eastern Senegal, a smallholder farming community with a highly diversified farming system in an area undergoing important socio-economic transformations and expected to experience high climatic variability.

Research aims

The research questions that guide this thesis are framed around the assumption that crop diversity plays a key role in increasing the resilience of farming systems to climate change and other stresses. In this context, I delve into cross-scale multi-facet causes and implications of local crop diversity dynamics.

The overarching aim of this thesis is to understand, within a context of small-scale farming, why and how crop diversity changes and what such changes imply for climate resilience. To understand the leeway available to smallholder farmers for decision-making concerning crop diversity, I first situate crop diversity in a specific biocultural context and in relation to the broader environmental and socio-economic changes affecting smallholder farmers. To analyse crop diversity dynamics, I then focus on two main aspects of farmers' practices and decision-making: crop choice and seed access.

Considering the overarching aims, the specific research questions of this thesis provide various layers of understanding of the interplay between climate change, smallholder farmers' decision-making, and crop diversity dynamics (see Figure 1.1).

Specifically, the empirical chapters are structured around the following research questions:

1) How do farmers perceive climate change impacts? And from their perspective, how important is climate change compared to other factors affecting smallholder farming systems?
2) How does climate change interact with other socio-economic and ecological drivers of change across scales and time? How does such interplay affect the way farmers manage crop diversity?
3) Do farmers adjust their crop diversity portfolios to react to the drivers affecting local farming systems? If so, how are these adjustments affected by the synergies and trade-offs between climate- and non-climate drivers?
4) How do seed networks affect farmers' adjustments in on-farm portfolios of crop diversity? What factors influence the structure and dynamics of seeds networks?

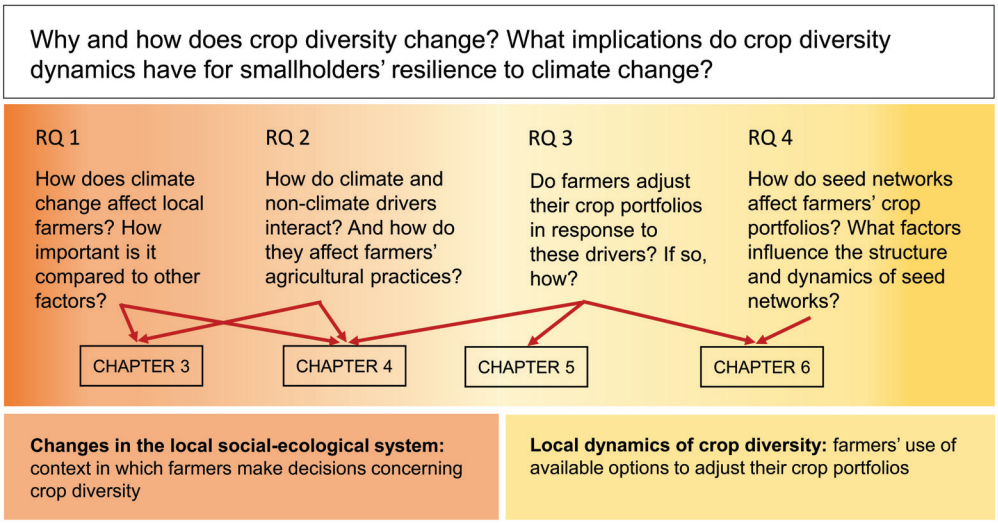


Figure 1.1: Overview of the chapters and research questions (RQ).

In the sections that follow, I set the context for the key arguments put forward in the dissertation. The introduction is organized around two chapters. The first chapter provides the background to locate my research disciplinarily and theoretically. The scope of this first chapter is to highlight the research debates and gaps that have contributed to shape my research questions and my way of engaging with research on the interactions of climate and crop diversity. It also outlines the conceptual and theoretical framework that has guided the methodology and interpretation of the data. This chapter ends with a roadmap of the thesis and presents the primary arguments of this dissertation. The second introductory chapter describes the case-study region, methods used, and realities of ethnographic fieldwork in south-eastern Senegal, including my positionality.

Background

Crop diversity leverages the resilience of agroecosystems to climate and other changes

Change and disturbance are integral components of smallholder farming systems. These systems are constantly evolving, shaped by social, economic, and ecological conditions. In this context, resilience becomes a prominent property of the system (Darnhofer et al., 2016; Urruty et al., 2016; Meuwissen et al., 2019). For smallholder farms, resilience can be defined as the capacity to cope with change or disturbance, such as dry spells and droughts, without losing essential functions, the most important of which is crop production (Enfors and Gordon, 2007).

A substantial body of literature emphasizes the crucial role of crop diversity in improving the resilience of agroecoystems at different scales (from the field to the landscape) (Falco and Chavas, 2006; Cabell and Oelofse, 2012; Abson et al., 2013; Mijatović et al., 2013; Beillouin et al., 2019). Higher crop diversity can stabilize food production and income, making households less vulner-

able to environmental and market fluctuations, and limiting pests and disease outbreaks (Lin, 2011; Gaudin et al., 2015; Renard and Tilman, 2019; Bellon et al., 2020). Moreover, research shows that crop diversity also benefits human health and enhances soil fertility (Jarvis et al., 2011; Davis et al., 2012; Bezner et al., 2019), allowing more efficient use of resources and stabilizing the provision of ecosystem services over time (Beillouin et al., 2021).

In a context of high climate variability, the hypothesis that the diversity of cultivated plants has a stabilizing effect on agroecosystem productivity is receiving increasing attention (Vernooy, 2022; Renard et al., 2023). This hypothesis has been widely described for natural ecosystems, where more diverse ecosystems tend to have higher ecological stability (Tilman and Downing, 1994; Yachi and Loreau, 1999) and resilience to climatic fluctuations (Isbell et al., 2015). In agroecosystems, the insurance hypothesis is based on the premise that crop performance varies with year-to-year climatic conditions, and no single crop can perform well in all places and in all climatic conditions. In a diversified ecosystem, the poor harvest of one species (or variety) can be compensated by the better harvest of others. Moreover, simultaneously cultivating a diversity of crop species or varieties can help buffer the impact of climate variations, for example by retaining soil moisture or providing shade, thus limiting temperature extremes.

Recent attempts to evaluate the potential of crop diversity to buffer climate shocks in agroecosystems have found positive results (Falco and Chavas, 2008; Gaudin et al., 2015; Isbell et al., 2017; Renard et al., 2023). Ethnobiology research based on case-studies has also found that farmers rely on complementary species and varieties to help compensate the impact of extreme weather events (Matsuda, 2013; Snapp et al., 2019; Ruggieri et al., 2021).

While there is sufficient evidence to suggest that crop diversification can contribute to the resilience of agroecosystems to climate and socio-economic shocks and uncertainties, studies worldwide show that the crop portfolios that farmers prioritize do not always follow the strict crop-diversity rationality of the insurance hypothesis (Bezner Kerr, 2014; Meldrum et al., 2017). In the next section, I review literature on the main drivers that enable or hinder crop diversity in farmers' fields to develop on the complex and iterative nature of farmers' decision-making.

The myriad of changes affecting smallholder farming systems

Most of the world's crop diversity is found in the fields of smallholder farming communities in the Global South (Brush, 1995; Jarvis et al., 2008; Zimmerer and de Haan, 2017). For generations, smallholder farmers have relied on crop diversity to sustain their livelihoods and guarantee their food sovereignty, and –in many cases– they continue to do so (Altieri et al., 2012). The diversity of crops found nowadays in the fields of smallholder farmers is the outcome of a long co-evolution between local biotic and abiotic conditions and farmers' management practices (Leclerc and Coppens d'Eeckenbrugge, 2012). In this sense, to understand crop diversity dynamics does not suffice to understand the history of crops from an evolutionary biology point of view. We also need to understand the environment and societies in which these crops thrive.

Smallholder reliance on crop diversity has been explored through different lenses. These include the diversity of cultural practices and belief systems that rely on a diversity of crops (Howard, 2010); the importance of crops adapted to marginal stress-prone environments that help harnessing heterogeneous biophysical and climatic conditions (Altieri, 1999b; Altieri et al., 2015); non-dependence on commercial seeds and agrochemicals controlled by markets and corporations (Kloppenburg, 2016; van der Ploeg, 2021); and the insurance effect provided by diverse farming systems (Lin, 2011; Renard and Tilman, 2019). Farmers' decisions on which crops to grow, however, do not occur in a void but in interaction with changing environmental conditions and prevailing political-economic systems (Bezner Kerr, 2014; Flachs, 2019).

In a context of global environmental change, several direct and indirect drivers of change challenge the conservation of on-farm crop diversity. In many smallholder farming systems, agrarian dynamics have led to the homogenization and simplification of crop diversity (Maikhuri et al., 1997; Hellin and Higman, 2005; McLean-Rodríguez et al., 2019). While the drivers affecting each specific smallholder farming system are context-specific and respond to concrete historical, cultural, and environmental conditions, several common features can be distinguished. In particular, major drivers of crop diversity loss are related to the expansion of industrial agriculture and agriculture commodification, which relies on the intensification of production and the specialization towards a reduced number of crop species (Van de Wouw et al., 2010; Zimmerer, 2010).

The predominant hegemonic focus on uniformity has severely affected the cultivation and use of crop diversity worldwide (Zimmerer and de Haan, 2019). In smallholder farming systems of the Global South, the industrialization of global agricultural production was initiated during colonial times, with the imposition of commercial crop plantations, such as peanut in Senegal (Bernards, 2019), oil palms in Malaysia (Vijay et al., 2016), cocoa in Côte d'Ivoire (Losch, 2002), and clove in Madagascar (Danthu et al., 2014). Later, with the integration of colonized countries into the market economy, farmers continued to cultivate these export crops (Godoy, 1992).

For several decades, national and regional policies rooted in the Green Revolution (i.e., "new Green Revolutions") have continued to favour the cultivation of a limited number of high-input dependent crop species and varieties (Kijima et al., 2011; Bezner Kerr, 2012; Pingali, 2012). Specialization on a few crops has been supported by research agendas largely focused on optimizing the performance of just a few species (Pingali, 2012; IPBES-Food, 2016). Numerous case-studies show how, with the introduction of research-improved, high-yielding seeds farmers abandon their traditional crop species and landraces (Maikhuri et al., 1997; Negri, 2005). Crop diversity loss is further reinforced by other environmental, socio-economic, cultural, and political changes, including climate change, land-grabbing, dietary changes, demographic changes and rural–urban migration, urbanization, the expansion of infrastructure and technology, and off-farm livelihood activities (Zimmerer and de Haan, 2019).

At a finer scale, farmers control over access to and use of crop diversity is also affected by intersecting power asymmetries at the micro-level. These asymmetries encompass community and individual-level characteristics of social differentiation. The "smallholder farmers" group consists of highly

heterogeneous social backgrounds and characteristics, for which their decisions and constraints to cultivate crop diversity-rich farming systems are influenced by household- and individual-level characteristics such as gender, age, and wealth (Bezner Kerr, 2014; Bellon et al., 2020).

While the interplay of agricultural intensification with global and local change processes has led to significant loss of crop diversity, it is also clear that it has not entailed the complete erosion of crop diversity. Some research suggests that farmers have found how to adjust and incorporate crop diversity into intensified agricultural systems amidst global change processes (Zimmerer, 2013; Reyes-García et al., 2014). Worldwide, a myriad of plots and gardens serve as bastions for maintaining and reproducing crop diversity in smallholder farming systems (Ibarra et al., 2019; Mariel et al., 2023).

Intersectional research considering climate change along the myriad of stressors and power dynamics affecting smallholder farming systems is on the rise (Nyantakyi-Frimpong and Bezner Kerr, 2015; Räsänen et al., 2016; Ensor et al., 2019). However, such research has primarily centred on rural livelihoods and farming systems in general. Less is known about how the interplay between climate constraints and socio-economic and political drivers of vulnerability affecting smallholder farming systems play a role in shaping crop diversity. Given that not all crops interact with and are affected by changing ecologies and farm practices, markets, and policies in the same way (Richards, 2016; Fischer, 2021; Roman and Westengen, 2022), understanding changes in crop diversity requires understanding a crop's status, role, and meanings in its particular context/reality. In the next section, I delve into the intricate network of social and biological dimensions that contribute to shaping the status of a crop species or variety in a particular place and time.

Crops biocultural status: a web of material and immaterial relations

Agronomy and ecology research has largely focused on understanding crops as biological objects. Crops have functional characteristics or traits that through abiotic-biotic interactions affect not only their role in the agroecosystem but also the way the agroecosystem functions and crops (and agroecosystem's) capacity to adapt to environmental changes (Altieri, 1999a; Wood et al., 2015). Key physiological characteristics, such as nitrogen fixation capacity in leguminous crops, significantly impact soil biogeochemical processes (Bohlool et al., 1992; Chimonyo et al., 2019). Additionally, the adaptability of crop cycle length to local rainfall patterns plays a pivotal role in the success of rain-fed systems. This is specially relevant in a context of increasing climatic uncertainties (Barron et al., 2003; Marteau et al., 2011; Carr et al., 2022).

At the same time, crops functional traits mediate multi-species assemblages. For example, through the creation of certain microclimate or disturbance regimes, certain crops can enhance or hinder certain pollinators, the growth of other plant species, and soil macro- and micro-fauna (Tonhasca and Byrne, 1994; Scott and Freckleton, 2022). The functional traits of crops also mediate the capacity of agroecosystems to cope with change. For example, shifting to shorter-cycle crops and varieties is a widespread strategy for smallholder farmers to adapt to the shortening

of the rainy season (Cooper et al., 2008) and the intercropping of crops with different functional characteristics can help to increase yield stability and mitigate risk (Paut et al., 2020).

Crops are, however, more than just agronomic/biological objects. Humans and crops are in a constant process of co-evolution. Through selection, management, and uses, farmers' shape crop material properties and simultaneously, crop material properties influence farmers' practices and knowledge (Leclerc and Coppens d'Eeckenbrugge, 2012). Crops, therefore, have socio-economic and cultural characteristics that mould their role and meanings in a particular society (Howard, 2010; Salick et al., 1997).

For example, crops can embody cultural memory and contribute to the reinforcement of threatened senses of identity and place (Nazarea, 2006a; Nazarea et al., 2013). Due to their significance in food or ceremonial contexts, certain crops and specific varieties serve as a connection to the collective past and to ancestors (Caillon and Lanouguère-Bruneau, 2005; Soleri et al., 2008; Isakson, 2009; Garine et al., 2017). They can also be important political entities (Scott, 2017, 2009), such as crops that have been central to the colonial project, like cotton in India (Dejung, 2013), peanut in Senegal (Bernards, 2019), or to the advancement of the Green Revolution and market-led development, such as maize in South Africa (Fischer, 2021). In contrast, certain crops historically served as an assertion of local autonomy and allowed farmers to resist the vortex of colonization and market integration, such as the cultivation of cassava as a form of resistance to the colonial project and capitalist logics (Scott, 2009; Roman and Westengen, 2022) or the cultivation of African rice among West African farmers and slave communities as a form of cultural re-affirmation and resistance (Carney, 2002; Teeken et al., 2012; Richards, 2016).

The roles that specific crops take in societies are far from deterministic and are not bound to their material properties. Rather, they depend on context-specific human-crop relations, histories, and cross-scale agrarian dynamics. In South-Africa, for example, genetically modified maize varieties reflect corporate-control, while traditional and creolized varieties of maize reflect farmers' resistance to these processes (Fischer, 2021). A crop's status is highly dynamic and can rapidly evolve over time. For example, through the process of creolization, a variety that has evolved from research, can shift to being considered a local variety by the community once reproduced on-farm (Bellon and Risopoulos, 2001). A crop's status is also highly contextual as the experiences that link farmers and crops differ across contexts. Crop species and varieties do not mean the same for everyone, even within the same community. These different meanings attributed to crops by different people are materialized, for example, in the lack of consensus among farmers regarding the names of varieties (van Etten, 2006a; Sadiki et al., 2007).

In summary, previous work points to crops as irrevocably relational, moving beyond instrumental values and accounting for the dynamic biocultural status that crops or varieties can have in a particular community and agroecosystem. Understanding how and why certain crops gain a specific status in certain contexts entails looking at the interplay between political-economic

dynamics, biophysical characteristics of the agroecosystem, and crops material and immaterial properties. Among the many farmer-crop relationships that shape crop diversity and crop status in a particular place, the acquisition, use and exchange of seeds plays a key role. In the following section, I examine the role of social networks for acquiring and disseminating seeds (and associated knowledge) among farmers, and the factors influencing the structure and dynamics of these networks.

Supporting crop diversity in farmers' fields: the role of social networks

In the face of major ongoing ecological and socio-economic changes, farmers need to adapt their crop diversity management practices to rapidly changing conditions while simultaneously balancing their needs and aspirations. Access to seeds, cuttings, and other types of propagules (from here referred to as "seeds") is key for farmers to reproduce, maintain, and adapt their crop portfolios to a changing context while also fulfilling their needs (Pautasso et al., 2013; Coomes et al., 2015; McGuire and Sperling, 2016).

Advances in social network analysis (SNA)[1] have shown great promise in understanding the social dynamics influencing seed access and circulation within smallholder farming communities (Garine et al., 2018; Ricciardi, 2015; Labeyrie et al., 2016). Most SNA research has focused on describing and understanding network patterns of farmer seed systems, including the composition of the network (i.e., the actors involved) and the structure (i.e., the way these actors interact). SNA research has demonstrated that farmers not only mobilize their social network to recover seeds after a seed loss (Violon et al., 2016) but also to introduce new diversity in their farms (Rockenbauch et al., 2019; Mariel et al., 2022).

Farmers can acquire seeds through a wide range of channels, such as peers, local markets, agricultural extension services, NGOs, and other rural development actors (McGuire and Sperling, 2016). Research to-date has highlighted the permeability between official distribution channels and farmers' seed networks, challenging the current policy and research divide between so-called formal and informal seed systems (McGuire and Sperling, 2016). Empirical research shows that the diversity of seed distribution and exchange channels that farmers mobilize affects the types and diversity of crops and varieties that they have access to, and therefore, cultivate (Almekinders et al., 2021; Labeyrie et al., 2023). For example, farmers generally access traditional crop landraces from other farmers while research-improved varieties are generally accessed through private seed companies or agricultural extension services (Louwaars and Manicad, 2022).

[1] Social network analysis has its origins in the fields of sociology and anthropology. Although the idea that societies are made up of interrelated components is not new, the use of matrix algebra and graph theory to represent these relationships has advanced greatly since the 1950s. Social relationships are represented as ties and nodes, where ties represent the interactions between nodes. Nodes can be individuals, groups, or organizations. Interactions can include material or immaterial relations such as friendship, learning, and transference of material or financial resources. Specific statistical tests have been developed for the analysis of social networks (Borgatti et al., 2009). When applied to agroecosystems, a SNA approach focuses on the relationships between material resources (seeds), actors (farmers, NGOs, extension services, researchers, breeders) and institutions (rules and accepted norms that govern these interactions) (Labeyrie et al., 2021a).

Seed circulation is shaped by farmers' cultural identity, social organization, and their socio-economic attributes. Evidence shows that farmers generally access seed from farmers from the same social group. Gender (Abizaid et al., 2016), kinship (Delêtre et al., 2011), or ethno-linguistic communities (Labeyrie et al., 2014a) can play a significant role. Furthermore, privileged positions to access seeds have been linked to socio-economic characteristics at farm-level, such as the size of plots (Kawa et al., 2013), household wealth (Wencélius et al., 2016), and farmers' individual characteristics, such as social status (Thomas and Caillon, 2016) or level of expertise (Calvet-Mir et al., 2012).

Amidst socio-ecological transformations, research recognizes the importance of studying farmers' social networks to enhance their capacity for adaptation and resilience (Rockenbauch and Sakdapolrak, 2017; Labeyrie et al., 2021a; Westengen et al., 2023). Access to a diverse pool of crops and varieties helps smallholder farmers cope with change and disturbance, including climate variability. Social networks play a key role in enabling new adapted traits, varieties and crop species to make their way into farmers' fields (Ruggieri et al., 2021; Labeyrie et al., 2023). Thus, an emerging field within SNA explores which characteristics of seed networks can best support crop diversity-based farming systems, potentially contributing to strengthening farmers' capacity to manage and adjust to change. This field links theoretical insights from literature on social-ecological networks focused on the sustainable management of common pool resources, like fisheries (Barnes et al., 2017), to that of SNA and crop diversity management (Labeyrie et al., 2021a). Looking jointly at these two fields highlights two research gaps.

First, while the diversity of actors that are part of farmers' seed systems has been widely acknowledged, how the different types of relationships and interactions between farmers and other actors affect the resilience of seed systems[2] remains poorly understood. Network research applied to non-farming social-ecological systems has shown that the connectivity between actors is not the only factor that matters, and that specific actor network configurations can enhance or hinder resilience. For example, centralized management systems[3] can be very effective in solving simple problems or responding quickly to a shock (see Figure 1.2). However, such centralized systems are not as effective in solving complex management issues and can generate power asymmetries. Contrarily, a less centralized network that effectively connects actors at various management scales increases their capacity to cope with change and can lead to more democratic governance processes (Bodin and Crona, 2009; Bodin, 2017). Despite presenting promising possibilities in the field of seed circulation networks, these theoretical insights remain confined to conceptual hypothesis (Labeyrie et al., 2021a) and simulation models (Barbillon et al., 2015).

Second, the few studies empirically testing the relationship between farmers' network patterns, such as the number and type of connections in the network, and the crop diversity maintained

[2] A resilient seed system provides farmers' stable and inclusive access to quality seed while being able to rapidly recover from shocks and stress (Westengen et al., 2023).

[3] In centralized management systems a small number of actors act as hubs, playing a key role in the circulation of resources, information, or in governance mechanisms.

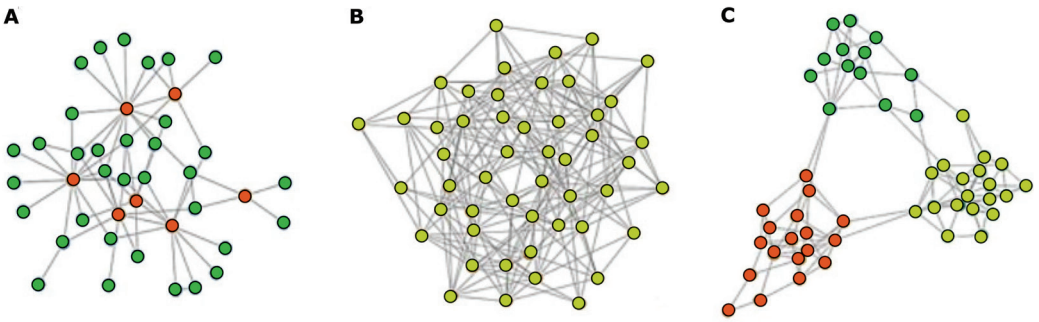


Figure 1.2: Illustrations of centralized (A) and non-centralized (B, C) social networks.

at household-level, found different results. For example, some case studies show a positive correlation between crop diversity and household centrality (Calvet-Mir et al., 2012) whereas others show the opposite (Kawa et al., 2013). While the inconsistency in results could be explained, at least partly, by the fact that the methods used were different, the type of network patterns that drive smallholders' access to a diversified pool of crops and varieties remain largely unexplored. Therefore, there is a need to gain deeper insight into the type of network patterns that contribute to enhance farmers' maintenance of on-farm crop diversity.

Seed circulation networks contribute to our understanding of the way crop diversity emerges and the way it is managed and maintained. Seed networks are widely influenced by the broader dynamics and context in which they are embedded. They operate not only within contemporary social and political conditions, but also within long-term historical and ecological processes. Such conditions and processes determine the practices and meanings surrounding seeds. Despite the mounting literature on social networks and crop diversity, there remains a need for a deeper understanding of the complex interplay between social and biological factors across scales and how they influence the way seeds are accessed, who holds control over them, and how they are distributed in farmers' fields. This gap points to the importance of taking multi-actor and multi-species approaches that consider the dynamic relations that engage farmers with their seeds and the myriad of actors involved in these relations. Such an approach necessarily entails recognizing the many ways of knowing that shape farmers relations with their crops and being attentive to how power is distributed. In the next section, I further develop the theoretical and analytical frameworks that have guided my research approach.

Theoretical framework

In this thesis, I study crop diversity dynamics under climate change. Among the many relations between farmers and their crops, I focus on crop choice and seed access, key aspects for the diversification and resilience of agroecosystems. To understand the interplay between crop choices,

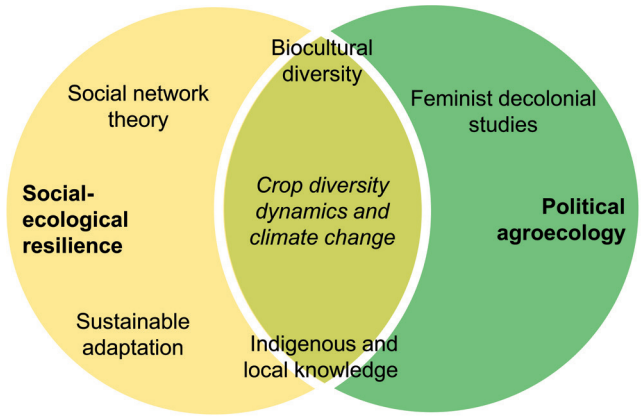


Figure 1.3: Diagram representing the main theoretical approaches used in this PhD thesis and their synergies and overlaps.

seed access and climate change, the theoretical framing of this thesis lies at the interface between resilience thinking and political agroecology studies. I mobilize these two frameworks in several interrelated ways that allow them to expand and cover gaps and limitations from each other. This thesis, however, spans the intersection between resilience and political agroecology by drawing on concepts and methods that, rooted in other fields, inhabit the space between them (see Figure 1.3).

Each chapter addresses different aspects and provides a different lens to understanding these interactions, namely: Indigenous and local knowledge (Chapter 3), feminist post- and decolonial studies (Chapter 3), sustainable adaptation (Chapter 4), social network theory/analysis (Chapter 6), and biocultural diversity (Chapter 6).

Thinking crop diversity and climate change at the interface of resilience and political agroecology

Social-ecological resilience

I use resilience thinking (*sensu* Folke et al., 2016) and the notion of social-ecological systems as a means to structure my understanding of change in agroecosystems. A resilience approach assumes that: 1) change is the only constant; 2) social and ecological aspects are deeply intertwined; 3) these aspects interact over time and across scales; 4) they interact through a process of coevolution, and 5) they are shaped by internal and external change drivers (Holling and Gunderson, 2002; Walker et al., 2004; Gallopín, 2006; Folke et al., 2010; Levin et al., 2013; Preiser et al., 2018).

Each chapter considers deeply intertwined social and ecological processes. In Chapters 3 and 4, the dynamic and close relationships between biological processes and socio-economic and cultural change processes are reflected in the conceptualization of climate change as a systemic problem. Climate change is addressed from a relational perspective and in conjunction with the many drivers affecting smallholder livelihoods. Chapters 5 and 6 look more deeply into the processes

and mechanisms that shape farmers' choices, seed access, and crop diversity at the local scale. Crops are examined from a holistic perspective, discussing how their biocultural status emerges through a range of ecological, social, economic, and cultural relations. Beyond acknowledging the multiple relations between climate, farmers and crops, transversal to my understanding of local crop diversity dynamics are also the social and ecological processes in which these relations are embedded. These processes act across scales and over time. I examine how the interplay between internal and external drivers of change shape farmers' crop diversity management practices and decision-making.

In the context of natural resource management, resilience scholars acknowledge the need to manage nature in ways that allow the needs of the present to be met without compromising those of the future (Folke et al., 2002). This perspective permeates throughout the thesis. I mobilize resilience perspectives, together with the notion of sustainable adaptation (*sensu* Eriksen et al., 2011) to conceptualize and assess the short- versus long-term implications of adjustments in local crop diversity portfolios. These analytical lenses helped me examine the tensions and trade-offs between climate- and non-climate drivers influencing farmers' decision-making, and triggered broader reflections on what current crop trajectories mean for future efforts to achieve resilient farming systems.

I also use resilience literature applied to agroecosystems to frame some pre-analytic assumptions about the interactions between crop diversity, climate change, and farmers' decision-making. The conceptual foundations of this thesis are based on: i) the crop diversity-stability hypothesis (Renard and Tilman, 2019), a pivotal concept in resilience literature dealing with agroecosystems, and ii) the idea that traditional crop diversity and farmers' knowledge are key sources of adaptation to climate change (Altieri et al., 2015; Altieri and Nicholls, 2017).

In sum, resilience provided me with the tools to think about change in agroecosystems in more concrete ways and set the foundations of my ideas concerning the type of change that is desirable and how it could be promoted in the case-study area. However, despite the potential of a resilience framework to encourage holistic, inter-disciplinary and inter-epistemological approaches to think about change and climate-crop diversity interactions, it lacks the critical theorisation around power, as highlighted in several critical works (Leach et al., 2010; Cretney, 2014).

Addressing power is critical to answer a bunch of questions I have asked myself throughout this PhD research journey, such as: What types of change are 'desirable'? 'Desirable' for whom? Under what conditions? Whose knowledge, worldviews, and visions shape my own meanings and ways of framing 'climate change', 'crop diversity' or 'resilience'? And if my meanings and theoretical standpoints reproduce and reinforce unequal power relations, what are the implications for academia and beyond? How do these knowledge and power asymmetries reinforce the status quo? Do they prevent thinking and action towards more just, fair, and sustainable agroecosystems? If so, what tools are there to change it?

Political agroecology

Political agroecology (*sensu* Gonzalez de Molina, 2013) offers a good background for thinking around such questions and for more nuanced interpretations on the interactions between crops,

climate, and social-ecological resilience. Political agroecology is the application of political ecology approaches to the study of agro-food systems (Gonzalez de Molina, 2013) and complements resilience by providing theoretical and empirical ground to conceptualize the interplay between social-ecological change drivers and power dimensions in agroecosystems.

I mobilize political agroecology as a holistic framework to address ecological and agronomic processes together with socio-economic dimensions of food production (Gliessman, 2014; Wezel et al., 2014; Bezner Kerr et al., 2021). Political agroecology literature aligns with biocultural approaches (Maffi, 2005; Caillon et al., 2017; Hanspach et al., 2020) and with literature regarding Indigenous and local knowledge (Berkes, 1999; Brondízio et al., 2021; Reyes-García et al., 2024a) on the importance of farmers' knowledge and of traditional crop species and varieties.

In this dissertation, I focus on the political agroecology of local crop diversity dynamics. I bring to the forefront the importance of historical forces and social inequalities to understand changes in farmers' crop portfolios. I conceive local crop diversity at the intersection between micro-level dynamics of resource access and control (e.g., intra-household gender roles affecting crop diversity decisions) and the broader political-economic changes and structures (e.g., state policies and knowledge hierarchies that affect farmers decision-making). I also delve into the, sometimes, conflicting roles of actors (e.g., kin, local communities, NGOs and development programs) and how these affect local ways of managing and accessing seeds.

The need to expand the scales of inquiry beyond categories like 'local', 'community' or 'household' are central to political (agro)ecology perspectives (Carney and Watts, 1990; Rocheleau, 2008; Razavi, 2009; Elmhirst, 2011). In this dissertation, I show how power dynamics involving income, labour relations and daily decisions on planting, eating and selling crops intersect with the dynamics of crop diversity (crop choice and seed access).

Finally, political agroecology, together with post and decolonial studies, draw attention to the frictions and dilemmas that arise as different ways of knowledge are brought into dialogue (Jasanoff, 2004; Blaser, 2013; Sundberg, 2014; Todd, 2016). This dissertation contributes with theoretical reflections on these frictions by paying attention to the research process and my own positionality as a researcher.

Merging these two theoretical frameworks and applying them to the understanding of crop diversity dynamics and climate resilience in south-eastern Senegal has shaped the ways I conceptualize crops and climate, and ultimately, my methodological choices. Instead of framing crop diversity and climate change solely from a biophysical perspective, I take a relational approach to crop-climate interactions, locating them within the lived experiences of smallholder farming communities. This approach to the conceptualization and analysis of contemporary crop diversity allows to contrast the questions that emerge when taking climate change as a starting point with the questions that emerge when accounting for cultural changes, social dynamics of household

reproduction, and rural political economies. The reflections of this thesis recast the discussion of resilience to climate change and other drivers of change in terms of how to maintain diverse and climate-adapted crop portfolios while fulfilling farmers' aspirations and needs within an increasingly market-driven society.

Thesis roadmap

This dissertation is a hybrid between a monograph and a compilation of peer-reviewed manuscripts related to each other. The four main empirical chapters have been independently published (three in journals and one in a book) and can be read as independent units. As such, there can be similarities between chapters in the description of the methods or the case-study area. The four empirical chapters are linked through comprehensive introduction, methodology and conclusion sections.

The main argument of this work is that smallholder Bassari farmers are narrowing their crop portfolios despite the critical importance of crop diversity for climate resilience. Several traditional crop species and landraces are disappearing from farmers' fields because of the effect of forces such as the market, changes in labour relations and changes in social relations. In this context, the understanding of farmers' practices, including crop choices and seed access, is vital to support smallholder farmers' crop diversity. I first analyse how the impacts of climate change interconnect with larger processes of change. I contextualize the contemporary farming system and livelihoods with the environmental pressures, historical elements and cultural meanings and practices. Against this backdrop, I look at how farmers adjust their crop diversity portfolios and the ways in which they access and share seeds.

Chapters 3 and 4 focus on environmental and socio-economic drivers of change affecting the Bassari territory and farming systems to set the context where farmers' practices and decision-making take place. Specifically, Chapter 3 documents Bassari observations of climate change and its impacts. Through a relational approach, I discuss how climate change is not the main and only driver affecting Bassari communities and can therefore not be treated as isolated from other processes. I discuss the need to take a relational view to understand how climate change is inextricably linked with the broader network of socio-economic and ecological processes taking place in the local communities.

In turn, Chapter 4 examines changes in Bassari agricultural practices and the relative importance of climate change in the context of multiple stressors affecting Bassari livelihood pathways. I focus on the interactions between biophysical and social drivers and how they shape farmers' responses and response options. Based on the benefits, costs, and trade-offs of changes in agricultural management practices for short- and long-term sustainability (incl. environmental, social, and economic dimensions) and for different social groups (incl. gender and wealth), I discuss what can and what cannot be considered a sustainable adaptation under climate change.

Following the argumentative line of Chapter 4, in Chapters 5 and 6, I examine how farmers adjust their crop portfolios and mobilize seed networks to access seeds. I then discuss how cur-

rent crop dynamics affect farmers' capacity to create, manage, or preserve crop diversity and agroecosystem's resilience in the long run. Both chapters examine the local dynamics for six crop species with distinct biocultural status. Specifically, Chapter 5 traces the trajectory of agricultural development policies in south-eastern Senegal together with the local dynamics of the six staple crops. The chapter explores how the political-economic dynamics of global agrarian transformations and environmental factors interact with household and community-level dynamics to shift cropping patterns over time. It illustrates how, despite local awareness of climate change impacts and because of stronger pressures from other drivers, rural communities might be adopting crop portfolios that increase their long-term vulnerability to climate change. It also shows how broad scale dynamics interact with household-level dynamics shaping crop diversity decisions.

Chapter 6, the last empirical chapter, explores factors guiding the structure and dynamics of seed circulation. I situate seed circulation networks at the intersection between the surrounding rural policy landscape and farmers' cultural identity and social organization. Based on my results, I highlight the importance of adopting a socio-historical perspective that allows understanding crops biocultural status and the constellation of actors that intervene in farmers' seed networks, as they affect the way farmers access crop diversity and, ultimately, the crop diversity found in farmers' fields.

Concluding this thesis, Chapter 7 integrates the main results of the four empirical chapters to provide a comprehensive overview of the main theoretical and methodological contributions of my research. It also addresses the policy implications that derive from my findings and offers insights into future research directions.

Finally, in the Appendices, I provide a list of publications that are complementary to this PhD project and further supplementary material of the empirical chapters of this thesis.

Chapter 2
Situating the research

Ge-tyasya (time to seed) starts

The third storm of June has provided a refreshing
break from the intense heat, prompting him
to breathe a sigh of relief in response.

For the first time this season, at last, the water
has seeped deep down into the soil and the
sweet smell of the earth floods my senses.

He looks at the sky, transfixed, and my eyes follow
his gaze. A tiny bird flits through the air. He nods,
as if the bird dance confirms his thoughts.

'The rainy season has begun', he murmurs: *'Those farmers who sowed after the first rain have seen their seeds burned under the heat of the sun. This year's late rains have tricked many of us'*.

Situating the research

This chapter aims to provide an overview of the geographical setting in which this work took place and the methodological approach used, including ethical considerations. Each empirical chapter will then expand on elements of the geographical setting important to follow the chapter's argument and will also provide a detailed account of the methods of data collection for the particular analysis. I close this chapter with a reflection on how my own positionality might have influenced the research process and the outcomes.

Case study description

The Bassari of south-eastern Senegal

I conducted research among the Bassari inhabiting south-eastern Senegal (see Figure 2.1). Bassari are an ethno-linguistic group of around 20,000 people living in south-eastern Senegal and northern Guinea. Together with the Bedik and the Coniagui, the Bassari belong to the Tenda-speaking people. According to oral traditions, Tenda were the first to inhabit the upper Gambia River region (Delacour, 1909; Kroot and Gokee, 2018). Nowadays, other ethnolinguistic groups, like the Fula, a traditional pastoralist group, inhabit villages neighbouring Bassari villages.

The study area is located near the Guinea border, below the Gambia River, in a hilly terrain formed by the northern foothills of the Fouta Djallon Massif, covered by the south-Sudanese wooded savannah. The area is bounded to the west and north by the Niokolo Koba National Park. A paved road connects the departmental capital, Kedougou, with the market town of Salemata, which is about 11-13 kilometres away from the communities where I worked. Access to the case-study communities is by an unpaved road and can be limited or temporarily closed during the rainy season.

The region is characterised by low altitude (approx. 80-380 m a.s.l.), a tropical dry or savannah climate, annual mean temperatures around 28 ºC, and an unimodal rainy season from May to September dominated by the West African monsoon system (Sultan and Janicot, 2003; ANACIM, 2020). Merely 10 % of the Bassari region's land is under cultivation. The rest encompasses vast forests and bushlands, serving as habitat for diverse wildlife and flora (UNESCO, 2011). Most agriculture-related work occurs in the short rainy season, whereas most off-farm work and income diversification activities occur during the longer dry season.

Bassari live in one of the poorest regions of Senegal, with limited access to public health and education. The region is one of the most rural and least populated, with 11 inhabitants/km^2 compared to the national mean of 82 inhabitants/km^2. People obtain water from wells and access to electricity is limited to the very few who have solar panels (ARD, 2018).

The largest Bassari villages have an unpaved road that allows motorbike or tuk-tuk transportation to the market town. Once a week, on market day, from sunrise until midday, tuk-tuks transport

people from the largest Bassari villages to the market. Houses are traditionally constructed with stone, mud, and straw/dry grass. A few wealthier households construct houses using concrete and metallic roofs.

Bassari families obtain most of their food needs from subsistence farming, which they complement with edible wild plant gathering, sporadic hunting, and purchase of other first-need products such as sugar, bread, rice, spices, cola-nut, tea, and processed products. To buy these products, Bassari women frequent the weekly market in Salemata or the few small shops present in the largest Bassari villages. Weekly markets in the Bassari territory were created during colonial times (Fouchier, 1981). Beyond providing a place for the exchange or trade of products (mostly food), weekly markets also have an important ludic and information-sharing purpose. The market is the main place for inter-ethnic contacts as it is attended by a diversity of ethnolinguistic groups living on both sides of the Guinea-Senegal border.

Historical accounts depict Bassari as hunter-gatherers and, until the 1900s, they maintained a semi-nomadic settlement pattern and self-sufficient lifestyle. According to oral tradition, Bassari moved their communities into more remote upland areas to avoid attacks from other ethnic groups. In the thirteenth and sixteenth centuries, they probably moved to protect themselves from the Malinké political hegemony (Person, 1984; Kroot and Gokee, 2018) and later moved to protect themselves from attacks of the Fula –led by Alpha Yaya–, coming from the Futa Jallon region, and which led to violent wars (Gomila and Ferry, 1966; Ferry, 1967; Gessain, 1975).

The 1900s marked an inflexion point in the Bassari territory, as under French colonial rule there was a distinct path of development. The French colonial period in the Bassari territory is characterized by the establishment of French schools, the presence of Catholic and Protestant missions, the introduction of a tax system, compulsory labour recruitment, and the expansion of peanut cultivation (Gessain, 1975). After Senegal Independence (1960), with the construction of roads, the development of tourism, and the increased presence of NGOs and development actors, the Bassari territory became increasingly integrated into mainstream market economy. Many Bassari households moved nearer to the road neighbouring Fula villages to be closer to infrastructures such as schools, stores, and health facilities.

Nowadays, while most Bassari engage in farming as a primary livelihood activity, almost all households combine farming with off-farm employment during the dry season. Off-farm activities include construction work, wage labour, crafts, and tourism. Hunting and wild edible plant and honey gathering are also important cash-generating activities. A growing number of Bassari men and women combine subsistence and economic activities in the Bassari territory with seasonal or long-term migration to the cities (mostly Dakar or Tambacounda, but also international migration). Working in the gold mines of the Kédougou region has also become a typical seasonal activity for the youth.

As the Bassari society and culture has changed, the environment inhabited by the Bassari has also undergone important changes. With a wetter climate than the northern regions, south-eastern Senegal was less affected by the Sahel droughts of the 1970s than most Senegalese regions. And

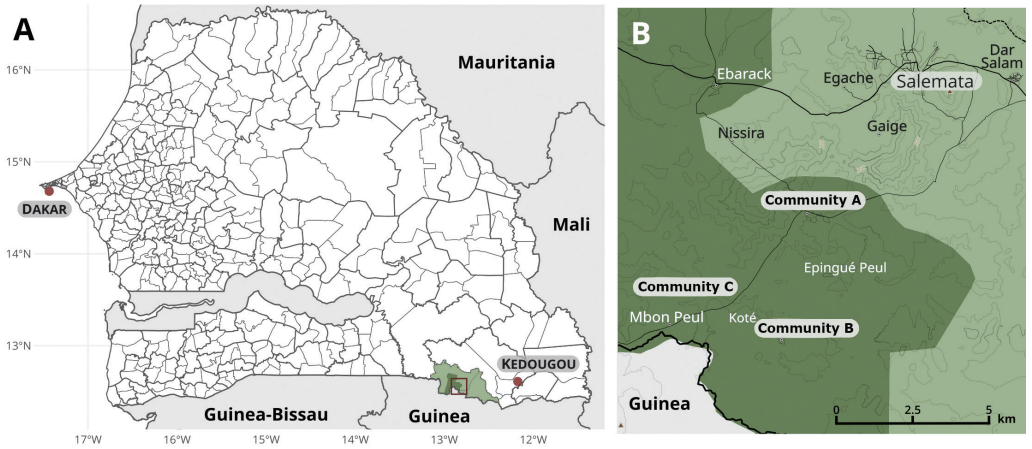


Figure 2.1: A) Map placing the study area within Senegal. The light and dark green polygons respectively represent the department of Salemata and the commune where the case-study communities are located. B) Case-study communities.

although there are important interannual rainfall variations, historical trends show a partial recovery of the lack of precipitation since the 90s onwards (ANACIM, 2020). Nonetheless, future climate predictions for the West African region indicate a trend towards higher temperatures and shorter rainy seasons (Sultan and Gaetani, 2016). Local people describe the gradual disappearance of forests and bushlands in favour of cultivated fields. They also report a decrease in abundance of plants, game, and fish species and the local extinction of some of these species.

Social organization

According to ethnographic work, the main organizing principles in Bassari society are residence, kinship, age, and sex (Gessain, 1975; Nolan, 1986). Singly and in combinations, these principles create a highly structured and socially compact web that link individuals together.

Bassari residence is mainly organized along two concepts: village (*angwol*) and neighbourhood (*andyana*). Neighbourhoods are semi-independent units that can be geographically separated from each other by several kilometres. Households, even within the same neighbourhood, are very dispersed in the landscape. While village residence is important for administrative issues (e.g., school attendance, access to health), agricultural communal labour is mainly organized around neighbourhood membership. Village residency is also related with marriage patterns, which are patrilocal.

Households are the basic economic unit of food production and consumption. They may be monogamous or polygamous, and it is common that several generations live together, usually all members from the same extended kin group. The number of people living in a household varies depending on the size of the extended family, which usually includes a husband, his wives, and their respective children. Each adult member of the family has a hut (the husband has his own hut and his wives each have their own). In addition, the household is composed of other huts: a

Figure 2.2: Photo of a typical household in the Bassari territory.

kitchen hut, a granary hut, and small huts for domestic animals at night (goats, sheep, and chickens). In the past, the huts were small and the households periodically moved closer to new fields to cultivate, but as the people have become more settled in one place, the huts have become larger (see Figure 2.2).

Concerning kinship, Bassari society is traditionally organized according to matrilineages (*o-nung*) which, like residence and age-class, also serve to structure the social relationships among villagers (Gessain, 1975; Nolan, 1986). Important relationships within the matrilineage are with the mother's siblings. Matrilineage not only provides names. It can also drive the inheritance of certain goods, chiefdom succession, and access to certain types of land, such as rice fields (Di Muro, 2018). Compared to the importance that matrilineage seems to have had according to the ethnographies of the 20th century (Gessain, 1975), matrilineage seem to have lost importance in recent decades[4].

Age and sex are the basis of the age-class system. Bassari age-class is the central traditional village institution and plays a key role for the village authority and decision-making (Gessain, 1975; Nolan,

[4] Nowadays children tend to take the father's lineage name instead of the mother's, or sometimes they keep both and use them depending on the situation. For example, they will use the father's family name with officials, but the mother's family name with neighbours. Some families are also shifting away from matrilineal inheritance, and nowadays only some goods are still inherited through matrilineal lines. Based on my ethnographic insights, this could be related to the integration of the Bassari territory into the national economy (in Senegal, most ethnic groups are patrilineal, and the administration also follows patrilineal logics). Matrilineage maintains its ritual importance, such as for ownership and inheritance of sacrificial stones, or for ceremonies for the curing of certain illnesses that gather together close members of the same matrilineage (Di Muro, 2018).

1986). Progression in the age-class system entails conducting a series of tasks and rituals, where most privileges and authority come with age, and only upon satisfactory performance of age-grade obligations. These are different for men and women (Di Muro, 2018). While age-class remains an important institution structuring social relations, it has lost importance over the years (Yamada, 2007).

Nowadays, rural-urban migration and new socio-economic needs are creating new social organizations in Bassari villages, such as interest groups around NGOs, sports, and the church. The increased presence of NGOs and development projects in the area has led to the establishment of a number of GIEs (groups of economic interest, in French 'groupe d'intérêt économique'). GIEs are non-profit organizations that respond to the need of NGOs of organized counterparts and to villagers' need for access to credit for the implementation of projects and other interventions. Sports groups, mostly football, are also an important way of social organization among youth. Catholic and Protestant churches are gaining force in the communities, blending with the distinct worldview of the Bassari, which is based on the interconnections between supernatural forces, the human world, and the world of animals and plants.

Concerning gender, Bassari society is characterized by rigid gender-specific domains of ritual and economic activity. In the cultural domain, women occupy important positions. Matrilineage organization of rituals and ceremonies confer women an equal (or even more important) status than men (Di Muro, 2018). In the agricultural-sphere, women and men carry their agricultural activities independently. Women control the harvest of the crops they had sown, and some crops are gender-specific. In the domestic sphere, women bear the workload of reproductive activities and have lower levels of education.

Agricultural system

Bassari mostly rely on agriculture for subsistence and excess crops are sold in the local market. Cotton and horticultural crops are the only crops produced almost exclusively for cash. For this thesis, I focus on the six local staple crops: sorghum (*Sorghum bicolor*), Bambara groundnut (*Vigna subterranea*), fonio (*Digitaria exilis*), maize (*Zea mays*), rice (*Oryza sativa*), and peanut (*Arachis hypogaea*) (see Figure 2.3). Due to their different cultivation histories and biological characteristics, these crops have different biocultural traits and fulfil different agronomic, cultural, and symbolic functions in the Bassari farming system, which provides them with differential biocultural status.

Many of the broader social and environmental changes taking place in the Bassari society have been translated into changes in agricultural practices. While Bassari agriculture remains largely subsistence-based and un-mechanised, Bassari agricultural practices are rapidly changing. NGOs and agricultural extension projects are placing the Bassari territory in a particular agricultural development trajectory. The provision of chemical inputs and research-improved seeds of a limited number of crops is slowly shifting crop portfolios and Bassari traditional agricultural practices towards more chemical input-based modes of production (the history of local agricultural development is extensively explained in Chapter 5).

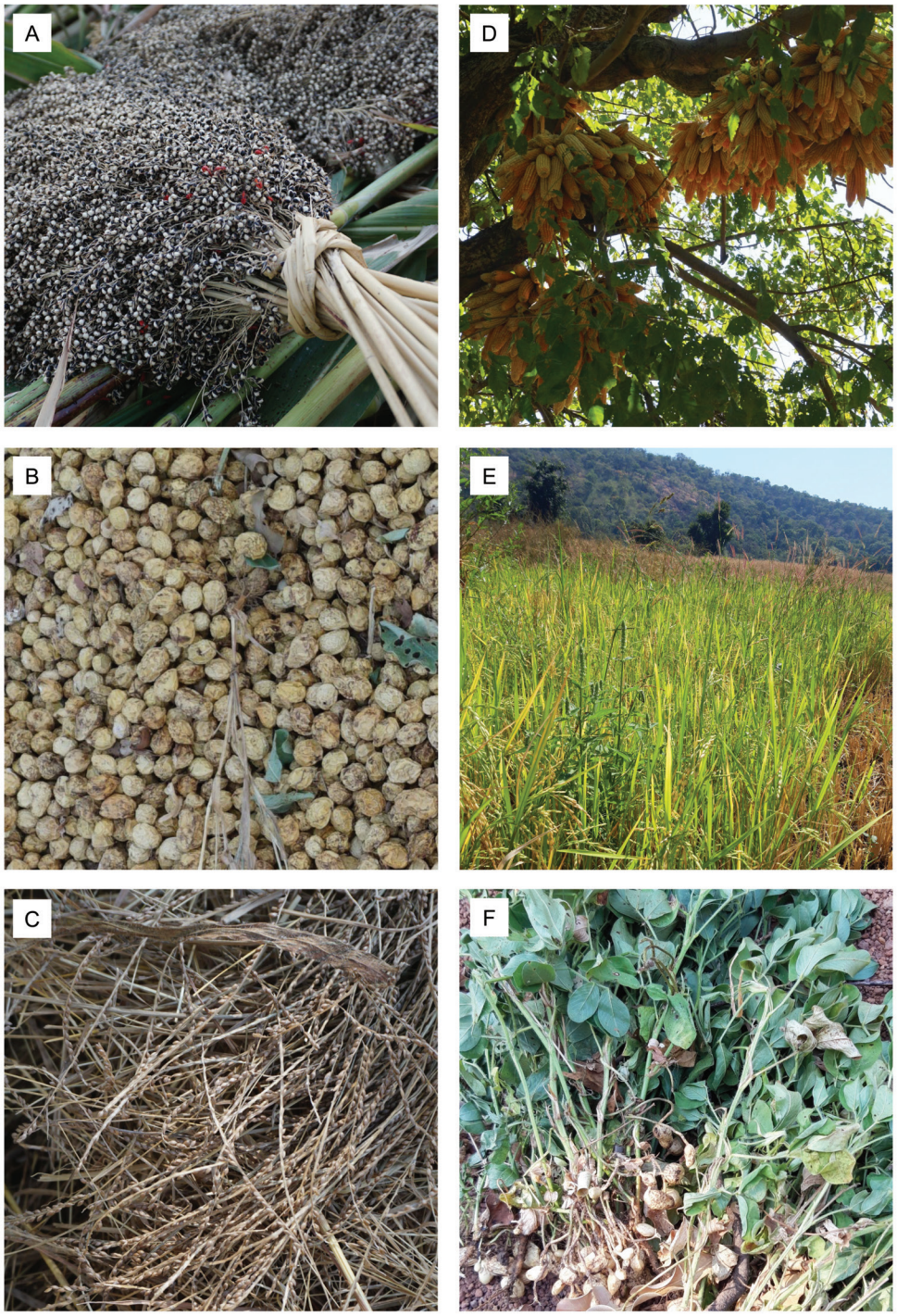


Figure 2.3: Bassari staple crops: A) sorghum, B) Bambara groundnut, C) fonio, D) maize, E) rice, and F) peanut.

Bassari practice slash-and-burn rain-fed farming, as is characteristic of traditional West African agriculture. This implies that the bulk of agricultural activities are concentrated during the rainy season and beginning and end of the dry season. The same plot is cultivated for several years, until the earth is exhausted; it is then left fallow for several years and a new field is created.

Households are the main unit for agricultural production. Each adult member of the household cultivates his or her own field, have their own granary, and control their harvest. In monogamous households, men and women usually work together in their respective fields, whereas in polygamous households women usually work their fields with the help of their sons and daughters. This system means that, within the same cropping season, households cultivate several fields, usually combining the cultivation of cereals and legumes. The fields cultivated by a household are not necessarily located nearby; they may be separated by a few kilometres and may follow different management systems, depending on the soil conditions.

Based on the type of soil and location, Bassari distinguish between three types of agricultural land (see Figure 2.4). The first local field type is *eden*, which are fields placed in soils rich in organic matter. They have a fine texture and are mostly located on the planes or valleys and near the streams. These soils are compact, thick, and blackish in colour. They sometimes show traces of hydromorphic conditions. *Eden* fields are cultivated year after year without crop rotation or fallow periods. In *eden* fields, Bassari distinguish between the parts where water remains stagnant during the rainy season and the parts that are humid but not stagnant. Rice is planted in the former and maize is planted in the latter. It is also in these soils where Bassari farmers plant tubercules, mostly taro, and in the dry season they are used for small-scale irrigated horticulture of lettuce, tomato, carrots, bitter aubergine, onions, and cabbages for local commercialization. These fields are sometimes fertilized, either with manure or with chemical fertilizer. Especially for rice, chemical herbicides are used. In the limits of these fields, it is common to find mango trees. The use of draft animals for ploughing is only common in rice fields, where the oxen-plough is widely used. For all the rest of crops cultivated in *eden* fields, the hand hoe (*daba*) remains the main tool used.

Oxenga, the second field type, are shallow soils. They are less rich in organic matter than *eden* and are mostly located on hilly terrains. This is the most abundant field type and it is where crop rotation takes place, followed by long fallow times (> 15 years). A traditional crop rotation includes the alternation of legumes and cereals. When an *oxenga* field is newly cleared, the first crops to be cultivated are peanut and/or Bambara groundnut, followed by sorghum, maize or cotton, and then again, legumes. A traditional rotation goes on for about 3-5 years. Fonio is usually the last crop in the rotation, due to the low moisture requirements, short growing season, and capacity to thrive in soils that are too depleted for the cultivation of other crops. Nowadays, in rotations, sorghum is being replaced by cotton and maize and Bambara groundnut by peanut.

Except cotton, that is highly dependent on external inputs, the crops grown in *oxenga* fields are grown without chemical fertilizer or pesticide applications. Given that the plough is unsuitable to cultivate this type of land (thin soils and hilly terrains), all agricultural work is done with the

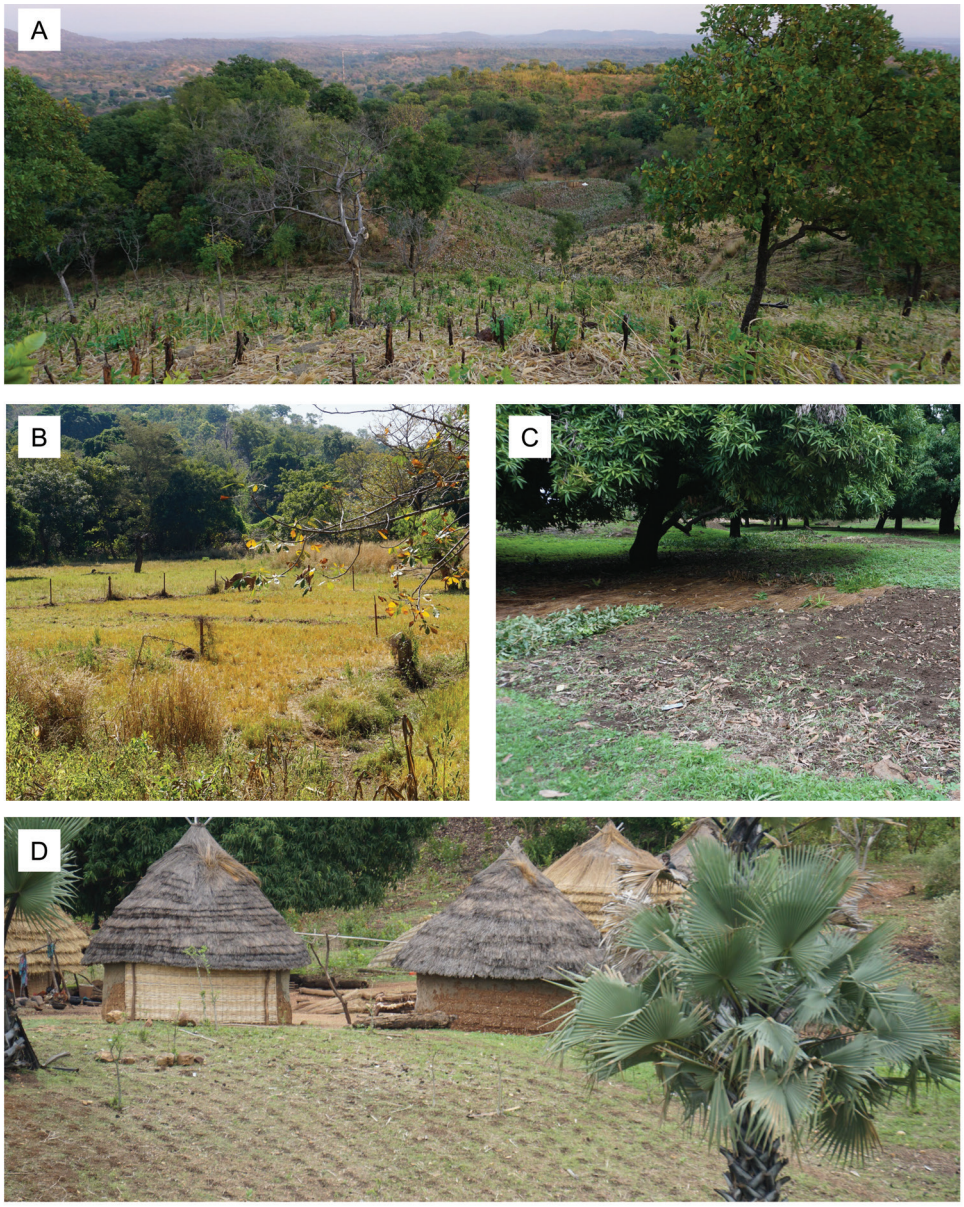


Figure 2.4: Main field types according to Bassari local taxonomy: A) *Oxenga*, B) inundated *eden*, C) non-inundadet *eden*, D) *enam*.

hand hoe. A high diversity of plants, including okra, hibiscus, haricot beans, pumpkin, tobacco, and different yam species, are either planted at the margins to delimit the fields or intercropped with main staples. The presence of multiple tree species, and particulary shea tree, *Lannea* sp. and *Hannoa undulata*, is also common in *oxenga* fields.

The land surrounding the houses is called *enam* and it is usually located in shallow soils, similar to the ones in *oxenga*. In *enam*, Bassari cultivate maize together with a wide diversity of complementary crops and fruit trees for kitchen needs. Some families also cultivate perennial cotton that they use for spinning and weaving their own tissues.

There is no official land titling and families have use rights over land. The rules guiding the inheritance of land-use rights is different for *oxenga* than for *eden*. *Oxenga* land-use rights are generally passed from a man to his sons, whereas for *eden*, use-rights are usually passed through the matrilineal line (*ayiw*). Land in the plains, however, is increasingly commodified and people start selling their *eden* plots.

Seeds are generally self-produced. Food shortages or climatic shocks, such as dry spells after planting, are important reasons for seed losses. Farmer-to-farmer seed exchanges are the most common way of seed provisioning. Cotton is the only crop for which seeds are always provided externally. Cotton seeds are generally given to farmers on the basis of a debt system together with chemical herbicides and fertilizers. For rice, maize, peanut, and horticultural crops, NGOs and agricultural extension projects are common providers of seeds. Local markets are also important sources of seed, especially for peanut.

Local agriculture is highly dependent on the use of shared labour and agricultural working days, which are mostly organized according to neighbourhood or age-class rituals. The use of hired labour, especially for cotton, is becoming increasingly popular.

Methodology

Methodological approach: weaving diverse ways of knowing

This thesis attempts to merge different ways of knowing[5] as meaningfully as possible. To do so, I bring the insights gained from studying local knowledge as a complementary, equally-valid source of evidence to understand local crop diversity dynamics amidst climate change (Tengö

[5] The diversity of crop species and varieties found nowadays have emerged from diverse ways of knowing. Farmers influenced crop diversity dynamics through the selection, management, and utilization of crop diversity. These diverse ways of knowing encompass the dynamic body of knowledge, practices, and beliefs and mediate the co-evolution between people and the environment, and between farmers and crop species (Berkes et al., 2000; Armitage, 2003; Nazarea, 2006c; Reyes-García et al., 2013). In this thesis 'non-Western knowledge systems' are also referred to as 'local ecological knowledge', 'traditional knowledge', 'Indigenous and local knowledge', 'farmers' knowledge' and 'situated knowledge'.

et al., 2014). However, rather than conceiving this methodological approach solely as a tool to build an 'enriched picture' and better understand complex socio-ecological problems, I consider it a precondition to ensure the quality of the research.

I build from previous academic work that has engaged more fully with non-Western knowledge systems, providing holistic and situated views on climate-crop interactions (Nkuba et al., 2020; Rarai et al., 2022). This entails recognizing the diversity of lifestyles and relationships between humans and crops as intrinsically bond to particular landscapes, cultural practices, beliefs, and symbolic dimensions. Acknowledging each knowledge system within its own context and values also involves reflecting on our (as Western researchers) own ontological and epistemological habits (Sundberg, 2014; Todd, 2015) and being as open and clear as possible on our limits for the understanding of local conceptualizations and realities.

While I strove to present farmers' voices as they were presented to me, this thesis should not be read as a reflection of Bassari knowledge and perspectives, but rather as an effort to understand, in a plural and situated way, farmers' decision-making and crop diversity dynamics in a climate change context. In the rest of this chapter, I delve into the research process and my own positionality, making it explicit from where I think, write, and engage with theory and practice.

General fieldwork description

Data collection for this PhD took place over a period of 16 months in two main field visits, from November 2019 to April 2020 and from September 2020 to June 2021. The fieldwork was interrupted by the Covid-19 pandemic.

Before starting the fieldwork, in April-May 2019, I conducted a one-month exploratory visit to south-eastern Senegal together with Vanesse Labeyrie, my PhD supervisor, to identify the case-study communities and establish the first contact with the local institutions and actors, as well as to conduct short exploratory interviews with local farmers. This first visit was crucial to refine and adapt my research questions and preliminary questionnaires to the realities of the field. During this trip, we visited several Bassari communities in the Kédougou region and met with the village heads of the potential case-study communities to expose our interest in working in the area and the objectives and framework of the research.

In late September 2019, I went back to Senegal. I initially spent 6 weeks in Dakar to solve logistical issues, strengthen local partnerships, and gather historical information from the Kédougou region. During this period, I consolidated my collaboration with the local institution (ISRA-BAME). I also conducted archival research in the National Archives of Senegal, the Institut Fondamental de l'Afrique Noire (IFAN) and in the central library of the Cheikh Anta Diop university, to obtain information on the pre-colonial, colonial, and post-colonial agricultural practices in the case-study area and to review agricultural policies and statistics.

In early November 2019, I travelled to south-eastern Senegal together with my partner and Mouhamed Rassoul Sy, a researcher from ISRA-BAME who accompanied us for the first week in

the field. Upon arrival, we organized assemblies with the three selected case-study communities where we presented the nature of our research and requested permission to work. We invited official and customary authorities as well as men and women representatives selected by the village head. At these meetings, we also discussed logistical matters about the conditions of our work.

We agreed that, when working in each case-study community, we would be accompanied by local interpreters from that community. We also discussed the characteristics needed for the interpreters: ability to communicate well in French, possibility to spend the whole day away from home or domestic duties, and having finished secondary school. We also required a gender balance. On this basis, the village authorities selected the interpreters. I worked with the same interpreters throughout the duration of the first research phase. Only when one of them was sick or had other duties did I engage other people. After Covid-19, one of the interpreters left the team for personal reasons and I engaged a new person, someone I had met through my personal network in the communities.

Until we received authorization to live and work in the communities, we lived in a tourist camp close by. We were assigned a host-family chosen by the village head and customary authorities. We made our home in one of the huts of the household. For logistic reasons, we lived in this community (Community A in Figure 2.1) for the complete study period. We established a very good relationship with our host family and the neighbours, and our hut was well-placed in terms of connection to the market town (approx. 2 hours by foot) and to communities B and C (max. 2 hours by foot). We also invested in setting up a comfortable living space; this would have been difficult to replicate in each case-study community.

The days I worked in communities B or C, I walked there in the morning and returned to community A in the evening. At first, I was always accompanied by the local interpreter or some of the children from our host-family, but later, as the area was calm security-wise, I made these trips alone and met the interpreters directly in community B or C. Only sporadically, when it got too late to go back, did I spend the night in communities B or C.

We remained in the community until April 2020, when, due to the Covid-19 pandemic, we had to be repatriated. During these first 6-months of fieldwork I mainly focused on doing ethnographic explorations. I conducted a first village census and became familiarized with the villages' social organization, the local language, and the geography of the area. I also conducted semi-structured interviews and focus group discussions. Together with another of my supervisors, Victoria Reyes-García, who visited us for some days, we tested and refined survey protocols. I had just started conducting the first bunch of surveys when fieldwork was interrupted by the pandemic and I had to return home.

Due to Covid-19 travel restrictions, I was unable to go back to the field until September 2020. Upon return, we stayed in community A for 10 months. Before going back to the case-study communities, my partner and I spent 20 days following strict confinement rules in Dakar to avoid any possibility of bringing the Covid-19 to the case-study communities. We went back to the field accompanied by Ndèye Fatou Faye, my third PhD supervisor. Upon arrival, we organized a community meeting to inform everyone that we were back and safe and ready to pursue our work.

We established ourselves again in the same hut and with the same host-family as previously. During this time, the main focus was on collecting quantitative data. I conducted household and individual surveys and crop diversity inventories. This 10-month period was only interrupted on two occasions when we travelled for a few days to Kédougou for visa issues. We also used these visits to the administrative town to buy material, communicate with my PhD supervisors, back-up the data in the cloud, and interview agricultural extension officers, local government officials, and NGO workers.

I completed the fieldwork with a large meeting in each of the case-study communities. At these gatherings, I presented a summarised version of the preliminary findings so as to hear villagers' reactions, opinions, and criticisms. Most reactions to my preliminary findings were of agreement, or the participants added details to one aspect or another. This event was more a mutual 'thank you and goodbye' than an effective exercise to collect feedback.

I had planned a third and last visit to the case-study communities to return the final results, verify interpretations, and think collectively in the ways to use the results of my thesis for local policy advancements. I also wanted to use this visit to present the results to local institutions with whom I had worked or collaborated during fieldwork. However, my personal situation (pregnancy and motherhood) did not allow it at the planned moment, and this final visit is pending.

Case study selection

The study site was chosen based on several considerations. First, I selected the Bassari for being a smallholder farming society that maintains a wide range of native crop diversity. Bassari were among the first ethnolinguistic groups to settle in this region and this long-term interaction with the local environment has allowed them to develop a rich body of knowledge and to have a detailed appreciation of local changes. Conditions that could potentially help me understand the complexity of crop diversity dynamics and climate resilience.

Second, the topic on which I was interested was locally relevant. Bassari practice rain-fed crop diversity-based farming and live in an area where rainfall is predicted to decrease and be more variable. In this context, regional level agricultural statistics show significant changes in crop diversity portfolios, but the causes and consequences of these changes for climate resilience remain largely unexplored.

Third, due to the long-term presence in the research area of a group of ethnographers from the Musée de l'Homme in Paris, there is the rare availability of baseline ethnographic data with information referring to past crop diversity and associated management practices. This allowed me to set my research within the historical context of French colonial agricultural development and to follow it up until the contemporary period. Moreover, compared to other regions of Senegal that have been highly over-researched (e.g., the 'Bassin arachidier' and the Senegal fluvial valley), since the 1980s little research has been carried out in the Bassari region, and little attention has been focused on agriculture-related topics.

Most of my fieldwork took place in community A, with 109 households and where the largest ethnographic baseline data were available. I also worked in communities B and C, with 55 and 24 households respectively, for specific parts of the data collection where I needed larger samples.

To select the case-study communities, the first and most important criteria were that we would only work with communities that were interested in participating in the research project. Other selection criteria were the availability of baseline data and that communities were representative of socio-economic and cultural conditions of the Bassari territory. I also took logistic reasons into account and selected communities within a reasonable walking distance from each other.

Like most communities within the Bassari territory, selected case-study communities were mostly inhabited by people belonging to the Bassari ethnolinguistic group and followed a similar livelihood-portfolio. Given that there are no strong vertical gradients in the location of the communities that could affect the temperature, the precipitation, or the agroecological zonation, these variables were not considered for community selection. In the Bassari territory, the largest differences regarding social and ecological variables occur at neighbourhood- and household-levels. Variables of social differentiation within the communities, such as wealth or access to different field types, have been considered for household-level analyses.

Overview of data collection methods

To gain in-depth and grounded understandings of the biophysical and socio-economic conditions that shape local dynamics of crop diversity, I combined critical ethnography with more quantitative data collection methods and the reading of secondary sources. The methodology, thus, follows a mixed-method approach, combining qualitative and quantitative research methods and different types of data sources (i.e., background data and primary data). The specificities of research methods and the sampling strategies and data analysis used are specified in each of the empirical chapters.

Background data used includes: (i) Statistical data, including weather station data from 1922-2015 from the Kédougou weather station (ANACIM, 2020) and data on crop trends, from 1980-2022 (ANSD, 2023), (ii) baseline data regarding crop diversity cultivated in the Bassari territory in the past, which primarily consists of ethnographic records available for the period of 1949-1986 (Dupré, 1965; Gessain, 1975; Nolan, 1986), and (iii) historical texts and reports. Primary data used included focus group discussions, semi-structured interviews, surveys, and household crop diversity inventories (Table 2.1).

Living in community A, I had many opportunities to take part in community life. I participated in common agricultural working days, joined women to collect water at the wells, helped with the cooking, went to the market, played with the kids, or simply stopped by to talk to neighbours. These experiences, together with the numerous exchanges with my interpreters, highly enriched my insight and my understanding of local dynamics.

All data collection took place in Bassari language. Although many inhabitants in the case-study communities spoke some French, we decided to conduct all data collection in Bassari, their mother tongue, to ensure that questions were understood and answered in sufficient depth. Through the period of the thesis, I worked with 5 field assistants, 4 men and 1 women, who helped me translate the questions from French to Bassari and ensure that questions were culturally-appropriate and correctly translated and understood.

Table 2.1: Table summarising the main methods and data gathered and the corresponding empirical chapter where each type of data is used.

Time-frame	Method	Sample size	Main data gathered	Results chapter
Period 1, November 2019- April 2020				
	Semi-structured interviews	47 semi-structured interviews	Observations of climate change impacts	3, 4
			Perceived changes in crop diversity	3, 4
			Explanations of drivers leading to changes in crop diversity	3, 4
	Focus group discussions	3 focus groups, 69 participants	Consensus of the observations of climate change impacts gathered through semi-structured interviews	3
	Focus group discussions	2 focus groups, 23 participants	Consensus of local crop taxonomy to establish a reference list of local crop diversity at variety level	5, 6
	Household surveys	49 participants	Trends and drivers in crop diversity portfolios at household-level	5
Period 2, September 2020-June 2021				
	Individual surveys	176 participants	Level of familiarity and meanings around climate change	3
	Household surveys	117 households	Household seed acquisitions	6
	Crop diversity inventories	117 households	Household cultivated diversity at species and variety levels	6

All the interpreters were native of the Bassari territory and the case-study communities where we were working. None of them had previous experience in research and only one held a university degree. I devoted time to training them in qualitative and quantitative research methods and build common ground and understanding of research protocols and research ethics. Their contributions to this research go far beyond conducting surveys and interviews. Their interpretations and insight regarding Bassari culture and their capacity to develop rapport with the people helped this research enormously.

During the 16 months that I was in the field, I managed to reach a basic level of communication in the Bassari language that allowed me to understand the general meaning of conversations and communicate with local people. However, my level of the language was insufficient for qualitative interviewing, which requires understanding and interpretation of subtleties such as facial expressions, body language, tone of voice, and sense of humour.

Ethics

All the communities that participated in this research gave their consent to participate. The consent of the communities was collected during community meetings where I presented the research framework, objectives, and the types of data collected. Before the community meetings, I held meetings with each of the official and customary authorities of the community (i.e., *chefs de village*, *chefs coutumiers*, *chefs de quartier*) and departmental-level (i.e., *préfet*) to ask for permission to participate. Consent was also collected from each household and individual that participated in the research.

The research project was presented in the community every time it was requested. In the cases when, during the community meetings, community members presented doubts and concerns that I could not solve in the moment of the meeting, I provided as much time as they needed to conduct internal consultations, which in some cases extended over a couple weeks. Only when all the households from the community agreed to participate would the community participate in the research. In all cases, when a community showed willingness to participate in the research, we moved on to discuss the terms of the research more concretely. I then transferred these into a written protocol that outlined all the basic agreements that had been reached regarding how fieldwork and our stay in the community should take place. These more detailed discussions did not take place in the community meetings but in smaller meetings with all the official and customary authorities at community-level.

This protocol of agreements varied slightly depending on the community, but generally consisted of general rules concerning how fieldwork should proceed. These protocols included the following rules: (i) the village and neighbourhood heads should be announced in advance that we would be working in their community and neighbourhood, so that they could inform the people, (ii) research informants would never be paid in money, but I would, instead, bring a small courtesy present such as tea, sugar, soap or kola nut, (iii) participants could withdraw from the research at any moment, (iv) I would always be accompanied by a local interpreter while conducting research. The choice of the local interpreter would be only up to myself, but local authorities would orient me and propose potential candidates, (v) interpreters would be paid a monthly salary according to local standards and proportional to the days worked, (vi) timely payments would be made to community members for help with research tasks and logistics, such as cooking for the participants of a project or event and help with transport. These payments, however, would always be agreed upon previously and according to local standards.

These smaller meetings also served to balance expectations on my research and to collectively think of potential ways to give-back the research outcomes in a way that also benefits the community. For example, despite all my efforts to clarify the purpose and conditions of my research, it was common for community members to think there would be some kind of material benefits for participating in my study. These meetings, and many individual conversations held during the 16 months living in community, served to find alternative ways through which my research could contribute to community needs. The ways were many-fold and kept evolving during our time in the community. For example, in two of the communities where I worked, we elaborated a map that documented all the wells to highlight the precarious status of access to water in some neighbourhoods. The community

authorities used this map to ask local rural development authorities for improvements in access to water. Conducting archival research, I found many pictures from the 1900s of the local communities' ceremonial life and people. I scanned and printed these pictures and brought them to the respective communities so that they could stay in the community and reach the families of the people who appeared in the pictures. Also, for the purpose of our research, we elaborated a simple catalogue with pictures and the local and scientific names for each of the local crops and wild edible plants. We left a draft version of this catalogue in the school before leaving and we are currently elaborating the final version to take when I return to the field for the final restitution of the PhD results.

As far as possible, I also tried to be generous with my time and skills, providing assistance and help to people when I was asked. Many people from the communities came to us for help filling out their administrative documents. It was also common, especially among the children/youth of our neighbourhood, to come to our home for help with Spanish and maths homework. As another example, I helped a women's group write an application for funding to set up a local shea butter- transformation plant. Since we were among the only people with a large solar panel, our home also became a common place for people from the nearby neighbourhoods to come and charge their mobile phones.

Money was probably the most difficult issue to handle while in the field. For daily money issues, together with my partner, we established our own protocol to decide when/how much/for what to pay and for what not to pay. This protocol was constantly revised and updated, and I systematically noted all payments made; to whom, what for, and how much. Having this protocol consensuated and discussed in depth between the two of us helped us navigate and react coherently in situations requiring a spontaneous decision. We tried to follow local norms of conduct as closely as possible.

Concerning data management, I assumed full responsibility for deciding which information would be published. In some cases, even with consent, community members provided me with information I considered was sensitive or could put them at risk in the future and should not be published. More broadly, I designed my interview questions with a specific focus on ensuring that all questions were culturally-appropriate and I avoided the collection of sensitive data. All personal data from the interviews was anonymized at data-entry. Qualitative data recorded with a voice-recorder is only accessible to myself and password protected. All the data are saved in a secure research repository of the UAB. The data I collected did not include plant vouchers. For plant identification purposes we used a digital camera. This research was approved by the Ethics Committee of the Universitat Autònoma de Barcelona (CEEAH 4903 and CEEAH 4781).

Positionality

I agree with Donna Haraway when she states that only through the partial perspective will we be close to reaching an 'objective' view. Haraway emphasizes the importance of clearly articulating your starting standpoint, explicitly stating your own political positioning and the social relations through which knowledge emerges (Haraway, 1988). This section aims to explicitly outline my personal positionality and how it influenced my research process.

I come from a disciplinary background in natural sciences (biology, agroecology) but I have long-term field-work experience in Global South countries at the interface between agronomy and social sciences. Despite my background in natural sciences, my epistemological and methodological comfort zone is long-term qualitative research. This PhD research project was born from my interest to deepen my knowledge on agroecology-based methods and to study whether and how these could be a viable means to achieve more sustainable and fair food systems. My relationship with crop diversity goes beyond the idea of writing a thesis as I have always been attracted to and, in one way or another, engaged with agriculture and food production.

This PhD research project materialized when I joined the LICCI team. The LICCI project blended with my interests in understanding crop diversity dynamics and inter-disciplinary and cross-cultural work. Since many of the LICCI-related tasks were carried out simultaneously with my PhD research, each project was invariably influenced by the other. If I was preparing a presentation about giving-back to the local communities as part of the LICCI partners' training workshop one morning, that afternoon I was reflecting on how I could apply those principles to my PhD project.

Being part of the LICCI project greatly influenced the scope and methodological approach of this thesis. It brought to the forefront the urge to partner and learn from diverse ways of knowing. Thinking collectively about change can encourage moving beyond technical fixes to address current environmental and food system crises. However, while my initial expectations were high, the constraints during fieldwork while being part of an international research project made me realize that establishing a 'real' dialogue between different ways of knowing is not easy to achieve, and that it was beyond the possibilities of this PhD project.

My positionality while conducting this research has also been affected by some of the multiple axes of social differentiation that define my identity. Here, I will only mention some of these categories, specifically those I think were mostly mobilized in the research encounters of this PhD thesis. My own condition, that of a woman, researcher, white, young, from the Global North, and recently, mother of a special needs child, influenced everything: my research questions, my relationships and role during fieldwork, the information I had access to, the way I engaged with literature and current debates, and the time I could dedicate to research and the write-up of this thesis.

Fieldwork involves a constant negotiation between positioning oneself inside and outside the community. Inside the community, by participating in everyday community life and building friendships and trust relationships with the members of the community, and outside the community, by pursuing one's own research goals and setting certain boundaries to prevent getting fully emotionally and personally involved. Within this constantly dynamic interplay, I would say that in the context where I conducted fieldwork, I, as a researcher, represented mostly an outside perspective. My values, worldviews, and the opportunities and privileges that I have enjoyed throughout my life (including the conditions for conducting this PhD research) often stood in contrast (or contradicted) the realities I encountered in the Bassari territory.

As an outsider, my status in the local communities also changed and developed with time. While initially it stirred confusion: if I was not a tourist, if I was not working for an NGO, and if I did not belong to a Peace Corps or any church, what was I doing there, and why was I not leaving after a few days like most foreign visitors? And why did I ask so many (sometimes silly) questions? After some time, however, these suspicious looks began to be replaced by questions about my family, life, and farming in my hometown, and innumerable jokes about when I planned to stop studying and have children 'like a normal person'.

Before starting fieldwork, I was aware of the potential tensions that could surface while conducting research in a formerly colonized country, where race, culture, historical legacies, and power inequalities cannot be overlooked (Ahmed, 1996, 2007; Sundberg, 2004, 2014; Yang and Wayne, 2012; Hunt, 2014; Todd, 2015). There were some aspects of my position and what I represented in that particular context that were not easy to overcome and that often made me feel uncomfortable.

Historical legacies and contemporary politics of development affected my role and interactions in the local communities. For example, my presence in the case-study communities was quickly interpreted by villagers as related to an agricultural development project, which created initial expectations for material benefits from my research. At the same time, I was automatically considered to be more knowledgeable than local people, and my role as an outsider granted me access to spaces that would not be allowed for a local woman or for a person of my age. Even in my most egalitarian, humble, and transparent exchanges with local people (e.g., with my interpreters or with our host family), differences in privileges came into play. For example, I was able to live with them, while most probably none of them will ever be able to (legally) travel to my home country. During the most uncertain moments of Covid-19, when it was not yet clear where this pandemic would lead, I was able to leave south-eastern Senegal and fly home, where I had access to vaccines, a public health system, and guaranteed access to food, drinking water, and electricity. The uncertainty of Covid-19 pandemic would have felt very different had I stayed in south-eastern Senegal without these privileges.

Besides the many aspects of my position that I could not detach from as a researcher, I have the (perhaps naïve) conviction that if interactions with people are handled with transparency, humility, and given the necessary time, it is possible to overcome, at least partly, these asymmetric relational dynamics. This belief is closely tied to my personal background. I have spent a considerable part of my youth and early adulthood traveling and living abroad, exposing myself to environments where the translations between languages, cultures, and worldviews are the norm rather than the exception. So, I followed my intuitions and planned my fieldwork to allow enough time to adapt myself to the study area and to establish relationships of trust with the people. I made sure that in interviews, focus groups, and surveys there was always enough time to get to know each other and to establish trust with research participants. Some participants, at first, were sceptical of my intentions, but after this initial phase, most participants appeared relaxed with my presence and my questions.

While I cannot claim to have overcome all these fieldwork challenges, I endeavoured to conduct a rigorous, situated, inequality-aware, and ethically sensitive research process. I also tried to be accountable for my own epistemic and ontological habits. It is from this positionality that this thesis was written and it is considering this positionality that it should be read.

Chapter 3
"So many things have changed": Situated understandings of climate change impacts among the Bassari, south-eastern Senegal

This chapter corresponds to the article:

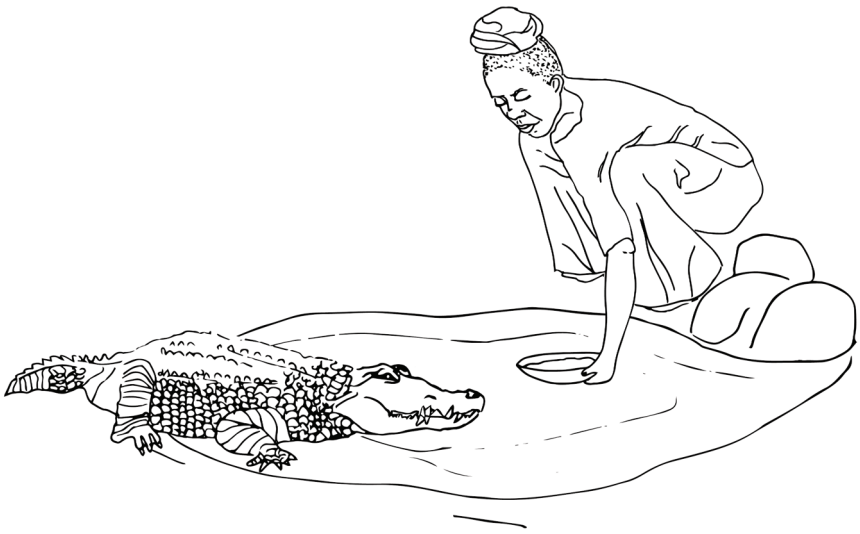
Porcuna-Ferrer, A., Calvet-Mir, L., Guillerminet, T., Alvarez-Fernandez, S., Labeyrie, V., Porcuna-Ferrer, E., Reyes-García, V., 2023. "So many things have changed": Situated understandings of climate change impacts among the Bassari, south-eastern Senegal. *Environmental Science and Policy*, 148, 103552. https://doi.org/10.1016/j.envsci.2023.103552

Ge-tyasya (time to seed)

I ask my interpreter about changes in the rainfall. He shrugs his shoulders, and adds thoughtfully: *'Those 'tubab'* [local word for Western people] *blame us for causing drought by burning the bush, but they are the ones who prevent water from falling by killing the crocodiles. These animals are at the source of the rain'* and with a big grin, he adds *'but what do I know? I thought it was you people who had all the answers!'*

I wanted to reassure him that his knowledge was not less but just different, and in this context, most probably better.

But I remained silent, and smiled back.



Abstract

Mainstream discourses frame anthropogenic climate change as a biophysical apolitical problem, thus privileging Western science and silencing other worldviews. Through a case study among the Bassari, an ethnic group in south-eastern Senegal, we assess the local, embodied, and situated understandings of climate change and the tensions that arise when the apolitical global climate change discourse interacts with situated understandings. Drawing on data from 47 semi-structured interviews and 176 surveys, we find that while the global climate change discourse has not permeated into the Bassari, they experience climate change through its many impacts on the biophysical and socio-economic systems. Results also highlight that climate is not considered the main or only driver of change, but that changes in elements of the climate system are inextricably linked with political and economic dynamics and environmental degradation. Finally, our results point towards the importance of values and supernatural forces in defining situated ways of conceptualizing, interpreting, and responding to change. By including situated worldviews in theoretical understandings of climate and environmental change, we contribute to the claims about the need to reframe how climate change is conceptualized. Our research emphasizes the importance of a relational view of climate change, which requires moving beyond understanding isolated climate change impacts towards defining climate change as a systemic problem. Building on feminist and decolonial literature, we argue for the need for more plural and democratic ways of thinking about climate change, crossing epistemological and ontological boundaries and including local communities and their knowledge and understandings.

Key words: climate justice, environmental change, epistemic justice, Indigenous and local knowledge, network analysis, plural ontologies

Introduction

> '*So many things have changed! (…) If I am correct, it's because of what we do with our own hands. Before, there would be sacrifices in each house to ask for the rain, or for the trees to give many flowers. (…). The world is changing, and mostly here. We cannot go against climate change, us Bassari'.*
> Bassari female elder, May 2021

Anthropogenic climate change is, perhaps, the most urgent global environmental problem, as it threatens life on Earth as we know it. Atmospheric changes have cascading effects on physical, biological, socio-economic, and cultural systems (Adger et al., 2013; Scheffers et al., 2016; Reyes-García et al., 2019).

Scientific explanations present anthropogenic climate change as a biophysical problem, relating it with greenhouse-gas emissions produced by fossil fuels (IPCC, 2021), with growing consensus about the diverse ways of experiencing climate change (Tschakert, 2012; Hohenthal et al., 2018; Rosengren, 2018). The opening quotation from our field research among the Bassari in south-eastern Senegal illustrates the complexity of local conceptualizations of climate change. It also reflects the tensions, discontinuities, and contradictions that emerge when contrasting local perspectives based on distinct cosmological, ontological, and epistemological grounds with the scientific discourse that dominates climate change debates.

Feminist, post and decolonial studies[1] and critical social scientists have a long tradition of uncovering the uneven power dynamics that shape what knowledge is considered legitimate, showing how power privileges Western science while dismissing other knowledge systems (e.g., McLeod, 2000; Jasanoff, 2004; Lizcano, 2006; Harding, 2009; Blaser, 2013; Todd, 2015). Accordingly, an increasing body of literature critically engages with climate change knowledge politics, analysing how knowledge is produced and whose knowledge and voices are heard (Hulme, 2010; Goldman et al., 2018; Mahony and Hulme, 2018). Overall, the global framing of climate change has favoured 'technical-biophysical' Western science views, which, despite being presented as objective and value-free, cannot be separated from colonialism, imperialism, patriarchy, and capitalist

[1] Feminist and post and decolonial studies come from very different traditions but are strongly complementary. They both include analysis of power, justice, and knowledge production, decentring the dominant ways of thinking. The feminist lens is crucial considering the historical marginalization of women from Western science and the importance of gender for knowledge production processes. The post and decolonial lens is key to understand how Western scientific knowledge production is deeply imbricated in imperial and colonial relations and their contemporary remnants. Both co-constitute each other by showing how the intersecting and multiple power hierarchies in which we live are crucial to understand how and why the voices of the most affected and marginalized by the colonial, patriarchal and capitalist system (i.e., non-Western local knowledge systems) are also the ones most silenced (Harding, 2009; Hunt, 2014; Todd, 2016).

resource extraction (Demeritt, 2001; Hulme, 2008; Bee et al., 2015; Nightingale et al., 2020). The Intergovernmental Panel on Climate Change (IPCC), a key institution in making and validating scientific climate change knowledge, is a good example of how certain voices are marginalized and suppressed from global climate change discourses. For example, through participation imbalances between Global North and Global South countries (Hulme and Mahony, 2010), male-dominance (Liverman et al., 2022), underrepresentation of humanities scholars (Corbera et al., 2016) and Indigenous and local knowledge (ILK) holders (Ford et al., 2016), or through the 'strategic unknowing', including denial, dismissal, diversion, and displacement of other ways of knowing (Arora-Jonsson and Wahlström, 2023).

Feminist post and decolonial studies advocate for collaboration across diverse ways of knowing in climate change research and policy, based on the principles of consent, cultural autonomy, and justice (Orlove et al., 2023), which ensures that gendered and power hierarchies are made visible, questioned, and addressed (MacGregor, 2009; Cameron, 2012; Bee et al., 2015; Carey et al., 2016; Todd, 2016). This entails learning from grounded and localised understandings of climate change and drawing attention to how climate change is differently lived and experienced by different subjects that, through their everyday practices, are located and bound to different power structures and inequalities[2] (Hulme, 2010; Brace and Geoghegan, 2011; Bee et al., 2015). Such an approach implies interpreting the physical dimensions of climate change through cultural meanings.[3] For example, by understanding 'weather', 'climate' and 'climate change' as ideas constructed through cultural practices (Hulme, 2008; Jasanoff, 2010). Thus, it is crucial to study how climate change is lived and interpreted by people within particular social and historical contexts and how climate change experiences and understandings fit into wider understandings of the world (MacGregor, 2009; Bee et al., 2015; Buechler and Hanson, 2015).

Berkes (2009) suggests that local understandings of environmental and climate change must be interpreted within the context of broader knowledge systems developed locally. Literature on ILK highlights the unique, complex, holistic, empirical knowledge that Indigenous peoples and local communities hold about climate and environmental variability, in which human-nature relations and values, knowledge, and behaviour are inextricably linked (Berkes and Berkes, 2009; Pyhälä et al., 2016; Reyes-García et al., 2016). In a similar vein, feminist studies refer to 'situated knowledge'[4], emphasizing that knowledge production is embedded in a particular language, culture, and contingent to the history and power relations of the knowledge-holder group (Haraway, 1988).

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[2] As opposed to universal global knowledge, feminist approaches emphasize the importance of looking at climate change knowledge production from the notions of 'embodiment' and the 'everyday'. By paying attention to the spaces of everyday practice and to the experiences and intersecting subjectivities (gender, class, race, indigeneity, and other dimension of power) of the situated bodies that live and produce climate change knowledge, a focus on 'everyday' and 'embodiment' make visible how broader uneven power relations shape mundane spaces and experiences around climate change (Bee et al., 2015).

[3] Previous research asserts that existing vernacular conceptions of climate and the environment (also referred as local cosmologies or ontological regimes) affect the way people perceive, experience, and react to environmental changes (Pyhälä et al., 2016).

Recognizing voices and knowledge systems marginalized by mainstream approaches allows to explore different ways of understanding climate change impacts, as well as a deeper understanding of the complex web of relations between climate change and cultural, political, socio-economic and environmental changes at the local, regional, and global scales (Boillat and Berkes, 2013; Li et al., 2021). Moreover, using multiple perspectives helps to think about the current gaps in climate science, question assumptions, and pose new questions –e.g., Nightingale, 2016; Goldman et al., 2018; Mahony and Hulme, 2018. While scholarly interest in introducing local worldviews into theoretical understandings of climate change is growing, the approach continues to be marginalized in global debates (Barnes et al., 2013; Castree et al., 2014; Reyes-García et al., 2019).

Building on previous work calling for epistemological and ontological plurality in understanding climate change (Orlove et al., 2023), our work aims at empirically exploring the local, embodied and situated understandings of climate change through a case study among the Bassari, an ethno-linguistic minority inhabiting south-eastern Senegal. To do so, we first investigate whether the global scientific concept of 'climate change' has made its way to the Bassari, and if so, who has access to this knowledge and how it merges with local notions of change, resulting in local meanings of 'climate change'. Then, we explore local reports of environmental changes and the perceived importance of climate change amongst other drivers of change. Finally, building on feminist and decolonial literature we discuss the frictions that arise when the apolitical, global, science-based framings of climate change interact with the local, embodied, and situated understandings of local communities with nature-dependent livelihoods. We consider the implications of these frictions for adaptation and climate change governance and argue for more diverse representations and conceptualizations of climate change.

Case study and methods

The Bassari of south-eastern Senegal

The Bassari country, southeast Senegal, is a region characterized by tropical savannah with dry-winter characteristics (Peel et al., 2007) and mean annual rainfall ca. 1172 mm (2005-2015) distributed along one rainy season (June-July to October-November) (ANACIM, 2020). The landscape and livelihood activities are determined by the yearly rhythm of dry and rainy seasons, which, as in the rest of the Sahel area, shows high inter-annual variability. During the 1970s and 1980s, the region was affected by intense droughts, and thereafter, there has been an increase in annual rainfall, widespread warming, and an increase in climate extremes (IPCC 2007, p. 299). These trends, however, are not clear, and climate change projections for the area remain uncertain and subject to large local variability (Sultan and Gaetani, 2016).

[4] We use the concept 'situated knowledge' (Haraway, 1988) to emphasize the extensive body of critical research that challenges the historical Western categorization of non-Western cultures as 'local', 'traditional', or 'Indigenous' while considering (Western) science as universal (e.g., Cameron, 2012; Todd, 2015). The notion of situated knowledge recognizes the knowledge-practice-belief complex is based on the multigenerational cultural transmission and evolving adaptive processes that characterize ILK (Berkes, 1999) and brings attention to colonial legacies and contemporary power dynamics.

Situated in one of the most remote regions of Senegal, the Bassari country has historically been socially, politically, and economically isolated from the rest of Senegal. Historical accounts depict the Bassari as hunter-gatherers and small-scale subsistence farmers, with dispersed settlement patterns and a self-sufficient lifestyle until the beginning of the 20th century. Most social changes in the area accelerated in the 20th century, with French colonialism and increasing integration into the mainstream market economy (Porcuna-Ferrer et al., 2024a).

French colonial rule (1900-1960) placed the Bassari territory in a particular development trajectory, characterized by the imposition of a tax-system, forced labour recruitments, the establishment of French schools and Catholic and Protestant missions, the creation of transport infrastructure and weekly markets, and the establishment of the Niokolo Koba National Park in an area traditionally used for hunting and gathering by local populations. After Senegal's independence (1960), the Bassari territory integration into the Senegalese economy continued through development projects and NGOs, which enhanced access to health and education and promoted agricultural mechanization, the use of chemical inputs, and new research-improved seed varieties. Small-scale tourism developed in the area in the 2000s, bolstered by UNESCO's designation of the Bassari Country as a World Heritage site.

The study area is located at the foothills of the Fouta-Djallon mountain range, below the Gambia river and is bounded to the west and north by the Niokolo Koba. A paved road connects the departmental capital, Kedougou, with the market town of Salemata (Figure 3.1). Nowadays, the main livelihood activity in the area is slash-and-burn agriculture, mostly for subsistence and cereal crops, with some legume and vegetable cultivation and cotton as the only cash-crop. Most Bassari families own some cattle as a cash-saving strategy. Bassari are increasingly involved in market-based economic activities such as construction, tourism, and gold mining (Porcuna-Ferrer et al., 2024a).

Methods

Data collection took place over 16 months between 2019 and 2021. We worked on three Bassari villages, with populations of approximately 200, 433, and 986 inhabitants, representing the area's diverse environmental and socioeconomic conditions. Using a combination of qualitative and quantitative methods (Reyes-García et al., 2023), we collected and interpreted data on Bassari familiarity with the Western concept of climate change as well as situated reports of environmental change. We collected data in French, with translations into Bassari by two experienced local research assistants, one man and one woman, who assisted us in ensuring that the questions were culturally-appropriate and correctly translated and understood. Research assistants belonged to the biggest village. When conducting research in the other two villages, a local interpreter belonging to each community also accompanied us. All members of the communities that participated in the research agreed research assistants and interpreters to be financed during the research period.

Before starting data collection, we obtained permission to conduct research from the official and customary authorities at village level (i.e., the *préfet*, the *chefs de village* and the *chefs coutumiers*) and each household and individual participating in the research. The research protocol was

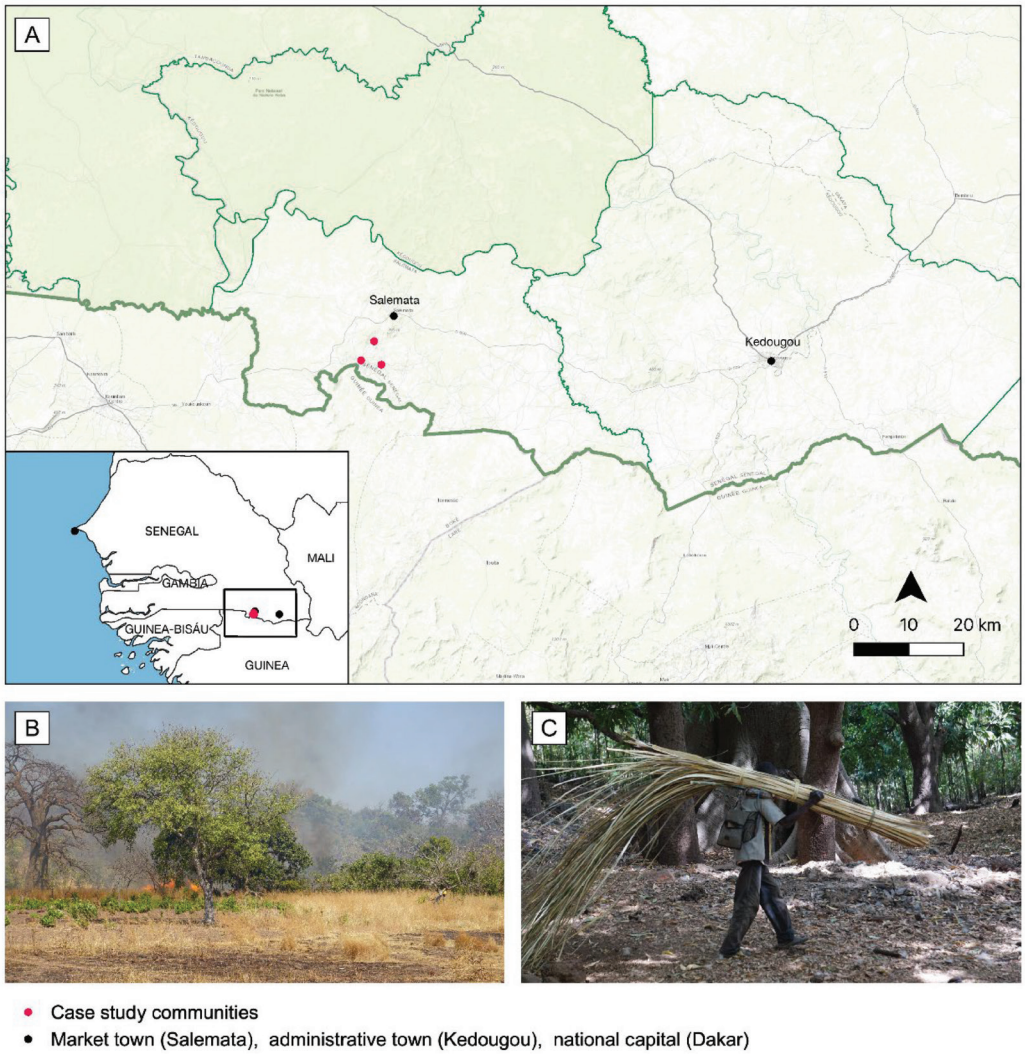

Figure 3.1: Location of the study area and illustrations of environmental changes reported by the Bassari. (A) Map of the study villages. (B) A spontaneous wildfire near a household. (C) A Bassari artisan transporting bamboo stripes for the construction of fences. Due to higher rates of resource extraction, the plant is becoming increasingly rare.

approved by the ethics committee of the Universitat Autònoma de Barcelona (CEEAH 4781). All authors of this paper are European, as such, we acknowledge that not being Bassari scholars might limit our understanding of Bassari knowledge and cosmologies, affecting our interpretations of Bassari reports of climate and environmental change and their drivers.

Bassari's familiarity with Western scientific notions of climate change

To explore whether the scientific concept of climate change had permeated in the local communities, we conducted a survey (n = 176). Participant selection followed stratified random sampling, balancing the number of selected individuals per case-study village, and gender and age quotas (Table 3.1). We asked survey participants: (i) have you heard the term 'climate change'? (yes/no); if yes: (ii) where did you learn about it? (i.e., TV, radio, other people, health post, school) and (iii) what does 'climate change' mean to you? (open text, documented verbatim). We also documented basic individual socio-demographic characteristics (i.e., biological sex, age, level of schooling, and village of residence).

We coded the answers into a variable called 'matching', which took the value of 'yes' if the interviewee referred to changes in the atmospheric system and (but not necessarily) CO_2 emissions or pollution; 'partially' if the interviewee referred to environmental changes potentially driven by changes in climate (e.g., crops produce lower yields, wild trees decrease production, etc.) but did not specify the driver; and 'no' if the interviewee mentioned changes that were not related to climate or environmental change (e.g., arrival of phones, radio, new crops, etc.).

We used percentages to quantify people's level of familiarity with scientific understandings of climate change and assessed whether responses to the variable 'matching' were associated to informants' sex, age and level of schooling. To test independence between response and explanatory variables, we used the Exact Fisher's test for categorical variables (i.e., sex and level of schooling) instead of a χ^2-test for which we had too few observations. A Kruskall-Wallis test was used for the numerical variable (i.e., age). The association between source of information and the variable 'matching' was assessed with a χ^2-test. In the text, we mention the test name when referring to the Kruskal-Wallis test or to χ^2-test; otherwise, p-values were obtained through the Exact Fisher's test.

All data analyses were run in R (R Core Team, 2021). We used the 'ggplot2' package (Wickham, 2016) and Inkscape v.1.2 for other visualizations.

Situated reports of environmental change and its drivers

We used a two-step process to assess situated reports of environmental change and the relative importance of climate change as a driver. We first conducted 47 semi-structured interviews (SSIs) with people locally recognized as knowledgeable, selecting individuals who could hold different knowledge on local environmental changes (Table 3.1). We tried to balance our sample across age, sex, and main livelihood activity, selecting the most common activities performed in the area (i.e., farming, hunter-gathering, fishing). Women participation was lower than desired (28 %), which we primarily attribute to the fact that, for logistical reasons, we had no option but to conduct SSIs during the main harvest time. Since women, besides being farmers also shoulder most responsibilities of household caregiving, they were less available than men for interviews.

Following Reyes-García et al. (2023), SSIs started with the question 'compared to your youth, what changes in the environment have you noticed?'; followed by questions about changes in a) the weather, seasons, temperature, rain; b) soils, river, and streams; c) wild plants, animals, and fish;

Table 3.1: Summary descriptive statistics of the sample composition.

Method	Sample size	Variable name	Descriptive statistics
Survey	176	Age	21 from 17-25 years (12%) 58 from 26-40 years (33%) 74 from 41-60 years (42%) 23from 61-100 years (13%)
		Sex	48% men 52% women
		Level of schooling	79 no schooling (45%) 59 primary school (34%) 21 middle school (12%) 13 high school (7%) 4 beyond high school (2%)
Semi-structured interview	47	Age	0 from 17-25 years (0%) 10 from 26-40 years (21%) 19 from 41-60 years (41%) 18 from 61-100 years (38%)
		Sex	72% men 28% women
Focus group discussions	69	Age	4 from 17-25 years (6%) 10 from 26-40 years (14%) 39 from 41-60 years (57%) 16 from 61-100 years (23%)
		Sex	49% men 51% women

and d) farming, livestock-keeping, or any other livelihood activities. For each change mentioned, we asked why the informant thought it happened and what was causing it. We then organized three focus group discussions, one in each village, to assess the community consensus regarding environmental changes and their drivers and to clarify unclear or contradictory observations.

Verbatim environmental change observations were coded into summary indicators following the hierarchical classification system proposed by Reyes-García et al. (2019), where environmental changes are classified according to the 'system' (i.e., atmospheric, physical, biological, socio-economic), 'sub-system' (e.g., temperature, terrestrial physical system, cultivated plant species) and 'impacted element' where they are observed (e.g., seasonal temperature, wild flora productivity, cultivated spp. productivity). For example, we coded similar expressions (e.g., 'now it rains less', 'it does not rain like before') into an indicator (i.e., 'changes in mean rainfall') which, following the classification used, was assigned to an impacted element ('mean precipitation'), a subsystem ('precipitation'), and a system ('atmospheric system').

When a change was reportedly driven by another environmental change, we used the same process to classify the driver. When drivers of change were not environmental, we drew on the IPBES classification of drivers, which distinguishes between 'direct' drivers of change (i.e., land-use change, resource extraction, pollution, invasive alien species) and 'indirect' drivers of change (i.e., values, demographic, technological, economic, governance) (Balvanera et al., 2019). We extended the IPBES classification by adding 'supernatural forces' as driver of environmental change (e.g., 'trees have stopped producing fruits as a punishment because now we sell their fruits', 'because of God'). To integrate both classification systems (IPBES and LICCI), we chose to work at the level with the highest correspondence between them, although we are aware that this correspondence is not exact.

We used network analysis to assess interactions between reported environmental change impacts and their drivers (Brandes and Erlebach, 2005), focusing on the relationships between changes rather than on the changes themselves. For this, we created an edge-list, with one column indicating the list of environmental change impacts and another indicating the reported drivers (adding one line per additionally reported drivers for the same impact). We only used impacts and drivers for which there was consensus in the focus group discussions. When visualizing the edge-list as a network, nodes represented either drivers or impacts of environmental change, and ties represented directed relations between nodes. So, an oriented tie from change (i) to change (j) indicated that change (i) drives change (j).

To analyse the network, we calculated two measures at the node and network levels: (i) *Indegree*. At node level, indegree, i.e., the number of incoming ties, represents the number of drivers reported for a particular change. At network level, a high indegree centralization indicates that a limited number of impacts are linked to many drivers while the rest are linked to a few. (ii) *Outdegree*. At node level, outdegree, i.e., the number of outgoing ties, represents the number of times a change is mentioned as driver. At the network level, high outdegree centralization indicates that a small group of drivers causes most impacts. We calculated all directed networks using the R package 'network' (Butts, 2015).

Results

Bassari's familiarity with Western scientific notions of climate change

Fifty-four percent of the sample (n = 176) reported hearing about climate change; but only 55 % of those provided a definition. 59 % of respondents who had never heard the term climate change were women, 68 % were over 40, and 58 % had never attended school (Figure 3.2).

Younger people (Kruskal-Wallis test, $p = 0.003$) and people with higher level of schooling were significantly more likely to have heard the term 'climate change' than their peers ($p < 0.05$). Everyone who had reached high school had heard about 'climate change'. We found no statistically significant relationship between gender and having heard the term climate change ($p > 0.05$). Men ($p = 0.02$), young people (Kruskal-Wallis test, $p = 0.02$), and people with schooling ($p < 0.05$) provided explanations that most closely matched scientific notions of 'climate change' (Figure 3.2).

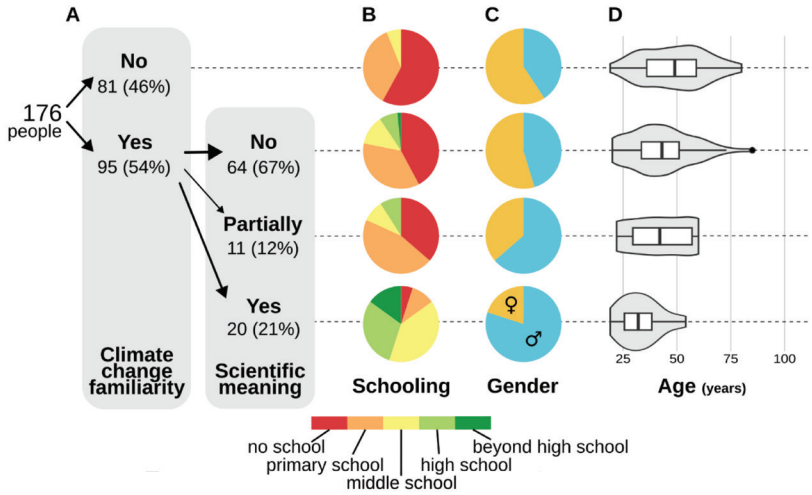

Figure 3.2: Socio-economic correlates to the local understanding of the scientific concept of 'climate change'. (A) The first bar displays familiarity with the term 'climate change', and the second matching between people's definitions and the scientific understandings of 'climate change'. Pie charts (B and C) and violin plots (D) represent the distribution of individual socio-demographic characteristics within each subgroup.

The most common sources of information about 'climate change' were other people (55% of the interviewees) and the radio (31%). Informants of different age, gender, and level of schooling used different sources. In general, men accessed climate change knowledge through the radio more often than women, who mostly accessed this knowledge by talking to other people ($p < 0.01$). Similarly, people who had completed middle school had heard about climate change at school, whereas people with no schooling generally accessed climate change knowledge by talking to other people ($p < 0.01$). We also found an association between the climate change knowledge source used and providing explanations that match Western scientific notions of 'climate change' ($p = 0.002$). Standardized residuals of the χ^2-test show a positive association between providing explanations of 'climate change' that do not match Western scientific meanings and relying on 'other people' as climate change information source (std.res = 3.66). On the contrary, providing climate change explanations that match Western scientific notions of climate change was positively associated with school attendance (std.res = 2.05) and access to TV (std.res = 2.49).

In explaining 'climate change', informants often referred to broader socio-economic changes affecting them (i.e., globalization and integration into market economy). From those that provided an explanation (n = 51), 48%, 41%, and 9% referred to atmospheric, socio-economic, and biological changes, respectively. Meanwhile, 14% of respondents referred to change in general. Only 17% referred to combined effects in more than one system. For some, 'climate change' was not an unprecedented phenomenon, but part of a cycle, like exemplified by the definition provided by a young male informant: '*Sometimes there is a lot of rain, sometimes not. The elders say there was a time when no rain came in a whole rainy season*' (Anonymous, April 2021).

When explaining the meaning of 'climate change', the most reported atmospheric changes were temperature increase, lack of rain, shift and shortening of the rainy season, drought, and general changes in weather patterns. Changes in the biological system included forest degradation, plant and animal diversity loss, and soil erosion, and those in the socio-economic system referred to changes in crop phenology or productivity, but also the increasing use of technologies, access and importance of money and material goods, pollution, dietary changes, and changes in knowledge access and circulation. Some informants also associated the concept of climate change with changes in habits and customs. Specifically, interviewees mentioned changes in the traditional value-system, abandonment of ancestral practices, and intensification of a utilitarian relationship towards nature. For example, one informant mentioned: '*There used to be a clan that was in charge of asking for the rain, but now they don't do it anymore, so the rain doesn't come*' (Anonymous, April 2021). Some informants also referred to super-natural forces and considered 'climate change' as their punishment. Bassari view spiritual beings as having a conscious agency in the physical world, which depends on the good relationship and mutual respect between humans and spiritual beings. In that sense, interviewees often referred to the punishment of 'super-natural forces' for the abusive or cultural disrespectful exploitation of nature. Like a middle-aged male explained: '*Nothing is like before; the people of nowadays are not anymore like the people of before. Before, there used to be more respect* [to the customs and traditions]*, now there is no respect. This is why things get worse*' (Anonymous, May 2021).

Bassari reports of environmental change

Beyond the definition of the term 'climate change' prompted in surveys, during SSIs and focus group discussions Bassari did report many environmental changes. Most observations referred to changes in the socio-economic system (37 % of the total), followed by changes in the physical (30 %), atmospheric (18 %), and biological systems (15 %) (Table 1s in Appendix 2).

Most changes in the atmospheric system referred to a decrease in precipitation, including changes in the abundance and distribution of rainfall and fog decrease. As a middle-aged woman described, 'N*owadays, it does not rain as before. Before, when the first rain arrived you knew there would be rain. Nowadays, sometimes the first rain arrives and there are four days without rain or even a whole month!'* and she continued *'Sometimes you could spend two or three days with 'okubina'* [specific type of fog], *but last year we did not even see it one day*' (Anonymous, January 2020). The general perception of a drier climate was noticed in the shortening of the rainy season (later onset, earlier end). Informants also mentioned temperature rises. Wind changes were rarely mentioned without prompting, but those who reported them provided extensive information about changes in wind strength and temperature.

Changes in the physical system related to river regimes, well depletion, soil erosion, and wildfires increase. During focus group discussions, hydrological changes seemed to be of especial concern, e.g., '*Behind my house there was a stream where we fished during the rainy season. It does not exist anymore*' (Anonymous, February 2020). Informants widely discussed the faster depletion of water in the wells, which posed problems, particularly for women, who are obliged to carry water from a greater distance. Furthermore, soils were said to have warmed up due to a lack of humidity. Decreased soil fertility was also reported, which informants closely linked with soil erosion: '*When we open a new field, it does not*

give like before. The soil is dry and tired (…). The wind and the strong rains take all the richness away. When a heavy rain comes, water cannot penetrate the soil and just runs off all the soil' (Anonymous, February 2020).

Interviewees also mentioned several changes in the biological system, with the disappearance of wild fauna as a major topic. Bush-meat plays a central role in Bassari culinary culture, but it is no longer (or rarely) consumed. Observers cited the local extinction of elephants, panthers, hyenas, hippopotamus, crocodiles and other large animals, as well as certain bird and fish species, which 'had run away'. Certain monkey species were also mentioned as having vanished, a local extinction seen as 'positive' since monkeys damage food crops. Concerns were also raised about the disappearance of certain wild plants; respondents mostly mentioned a decrease in edible species for household consumption and sale, such as baobab, weda or madd, shea tree and African locust bean, as well as trees and other species specially valued for their timber, such as the local raffia palm.

Bassari also mentioned changes in livelihood activities, primarily in agricultural practices. People were acutely aware of changes in crop sowing times, lower harvests due to drought, and increased crop pest pressure, particularly during grain storage. As a young woman farmer explained: '*Last year, I stored my peanuts in these recipients, and three months later, it was all powder!*' (Anonymous, February 2020). Interviewees also mentioned that livestock had to travel further to find fresh pasture and they all agreed that livestock epidemics were becoming more common.

A network of changes

Most reported changes drive other environmental changes. Only a few socio-economic changes were exclusively mentioned either as impacts (i.e., infrastructure and human health) or as drivers (i.e., governance, demographic, economic, supernatural forces) (Table 3.2).

In general, elements of the 'atmospheric' (32.1 % of observations) and 'socio-economic' systems (32.1 %) were reported in a higher number as drivers of environmental changes, compared to elements of the 'physical' (18.5 %) and 'biological' systems (17.3 %). Impacts on the 'socio-economic' (31.5 % of observations) and 'physical' systems (31.5 %) were more frequently reported than impacts on the 'biological' (23.5 %) and 'atmospheric' systems (13.6 %) (Figure 3.3).

Drivers of environmental change

The relationships among changes reported by the Bassari underscores the complex interrelations and multiple reinforcements among environmental change impacts and drivers (Figure 3.4).

The centralization outdegree score of the network was low (1.72 %), suggesting that the Bassari perceive many drivers of environmental change. Moreover, 65 % of the impacts mentioned were associated with more than one driver.

Our measure of nodes' outdegree suggests that water-related changes, specifically changes related to 'precipitation' and 'continental waters', were the most important drivers of environ-

Table 3.2: Categorization of subsystems according to whether they are only impacts, mostly impacts, mostly drivers, or only drivers.

Categorization	Subsystem	Ratio (indegree/outdegree)	Outdegree	Indegree
Only impacts	Infrastructure	Inf	0	2
	Human health	Inf	0	10
Mostly impacts	Pastures and grasslands	6.00	1	6
	Cultivated plant spp	5.00	4	20
	Freshwater fauna	3.00	2	6
	Terrestrial wild fauna	2.67	3	8
	Terrestrial wild flora	2.17	12	26
	Soil and land	2.09	11	23
	Temperature	2.00	1	2
	Continental waters	1.92	13	25
	Livestock	1.20	5	6
Mostly drivers	Air masses	0.57	7	4
	Land-use change	0.50	6	3
	Precipitation	0.30	40	12
	Resource extraction	0.17	12	2
	Pollution	0.17	6	1
	Values	0.11	9	1
	Technological	0.11	9	1
Only drivers	Governance	0	3	0
	Demographic	0	8	0
	Economic	0	4	0
	Supernatural forces	0	2	0

mental changes. Another important driver was ‘resource extraction’, which had the third highest outdegree (Table 3.3). The decrease in seasonal precipitation impacted a wide range of elements including wind temperature, aquifer recharge, wildfires, soil fertility, wild plants productivity and distribution, livestock, pasture availability, and crop yields and mortality. Given the local importance of farming, the effects of precipitation changes on the agricultural system were a common concern. As an old man explained: ‘*Before, there was less rain, but it would last for the whole day, we called it "tib ind eyam*" [= rain of the good harvest]. *Nowadays it rains for a shorter period of time but stronger and the rain takes away the soil and plants*’ (Anonymous, February 2020).

Changes in ‘continental waters’ (i.e., rivers and streams) were also reported to impact many other elements, including wild flora and fauna, pastures, crops, livestock, transport infrastructure, and human health. Interviewees also reported that the drying up of rivers resulted in temperature increase and changes in wind seasonal patterns.

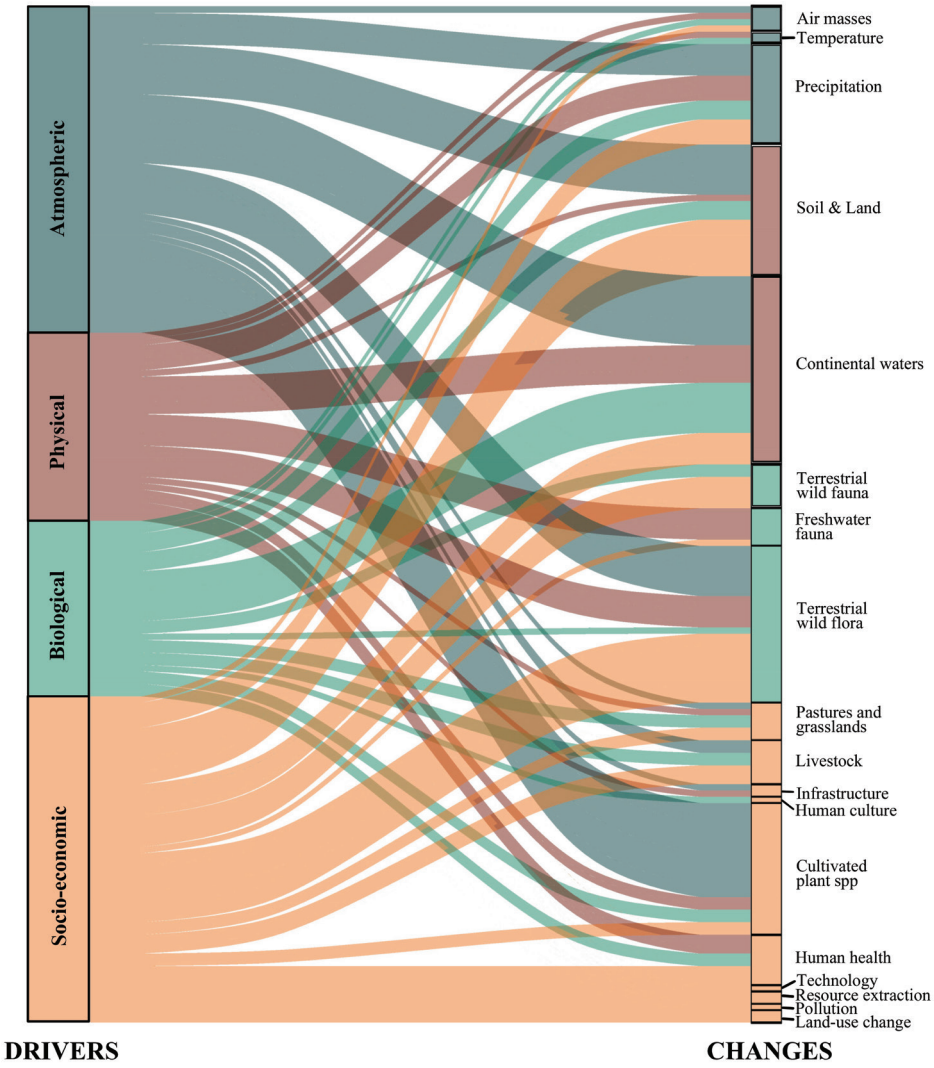

Figure 3.3: Sankey diagram showing the reported relation between atmospheric, physical, biological, socio-economic drivers and socio-environmental changes.

Bassari related increasing resource extraction with impacts on the atmospheric, physical and biological systems. In general, interviewees referred to the overexploitation of nature mostly through small-prey hunting (e.g., birds, small mammals), honey, palm-wine, wild edible fruits and timber harvesting, and well-water consumption. For the Bassari, intensification of species extraction drives defaunation and deforestation, as one of the interviewees explained: '*When the season comes, everybody goes in search of madd* [wild edible fruit with high market value]. *Before we would leave some fruits for the birds or animals to eat. Also, some fruits would fall near the mother*

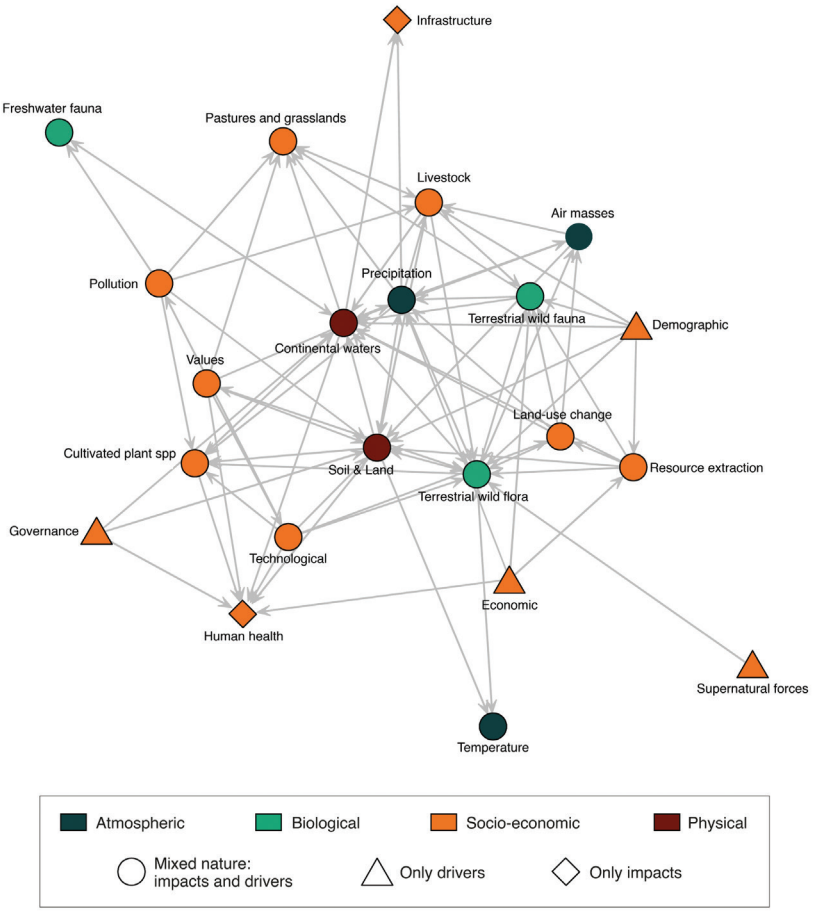

Figure 3.4: Network plot: representation of changes (drivers and impacts) collectively perceived by the Bassari.

tree and produce new seedlings. Now fruits do not reach the ground, that's why it's rare to see a small tree!' (Anonymous, March 2020). Bassari also related increasing extraction with rainfall decrease arguing that tree species that 'call for the rain' are now rare. As explained by an elder woman: '*The rain does not come like before because we cut many trees*' (Anonymous, February 2020). Moreover, as explained by a focus group discussion participant, the decrease in forest surface and river-bank vegetation also impoverishes local diets, as many wild edible plant species became rare.

Finally, some changes in elements of the socio-economic system were regarded as drivers of environmental change (Table 3.2). These include population growth and village expansion, access to services (e.g., schools, doctors) and material goods (e.g., solar panels), technological innovations (e.g., introduction of new crops and varieties, pesticides and fertilizers), land-use changes (e.g.,

Table 3.3: Ranking of indegree and outdegree values for each of the subsystems.

	Subsystems	
Rank	**Outdegree**	**Indegree**
1	Precipitation	Terrestrial wild flora
2	Continental waters	Continental waters
3	Resource extraction	Soil and land
4	Terrestrial wild flora	Cultivated plant spp
5	Soil and land	Precipitation
6	Values	Human health
7	Technological	Terrestrial wild fauna
8	Demographic	Pastures and grasslands
9	Air masses	Livestock
10	Pollution	Freshwater fauna
11	Land-use change	Air masses
12	Livestock	Land-use change
13	Cultivated plant spp	Infrastructure
14	Economic	Resource extraction
15	Governance	Temperature
16	Terrestrial wild fauna	Values
17	Freshwater fauna	Technological
18	Supernatural forces	Pollution
19	Temperature	Governance
20	Pastures and grasslands	Demographic
21	Infrastructure	Economic
22	Human health	Supernatural forces

agricultural expansion), and changes in governance and the economic regime. One interviewee, for example, explained land-use change as follows: '*If you go back 15 years from now, to go from our household to the household of X you had to cross a lot of bush. Today, all this bush are fields, and the land can't rest*' (Anonymous, February 2020). Bassari often refer to the shift in local values as a driver of change, and particularly the growing importance of money, the abandonment of local traditions, and the instrumentalization of nature. For example, some interviewees linked the decline in game productivity to abusive hunting, while others suggested that the decline in wild fruit productivity was a punishment for harvesting too much for commercialization: '*Trees do not give like before (...) because now people harvest to sell, not to eat. That's why trees have stopped giving*' (Anonymous, February 2020).

Impacts of environmental change

The centralization indegree score of the full network was low (1.06 %), indicating that there were many impacts connected to many drivers. According to the indegree node measure, the nodes impacted by the most drivers are 'terrestrial wild flora', 'continental waters', and 'soil and land'.

Changes in 'terrestrial wild flora' were reportedly driven by changes in the atmospheric, physical, and socio-economic systems, including precipitation decrease, temperature increase, decreased availability of continental waters, higher rates of species extraction, demographic and land-use changes, and changes in values. On the latter, one informant commented: '*We used to have ceremonies and many cultural practices for trees to give a lot of flowers. Now nobody practices them anymore, therefore trees give less fruits*' (Anonymous, December 2019). Some informants specially highlighted the impact that practices oriented to generate income have in wild flora: '*Nowadays people cut trees near the river because they only think of earning money. Those areas are forbidden by the tradition*' (Anonymous, December 2019).

Changes in 'continental waters' were allegedly driven by decreased precipitation, intensification of agricultural practices and livestock keeping, land-use change, and increased extraction of terrestrial wild flora. Increased resource extraction was also linked to the drying of rivers: '*We cut all the raphia. It was the raphia that retained the water*' (Anonymous, February 2020). The disappearance of freshwater fauna is also mentioned as a cause of river drying up.

Changes in 'soils and land' were reportedly driven by changes in rainfall and wind patterns, wild plant species abundance and distribution, and agricultural practice changes, such as shorter fallow periods, chemical inputs increasing, or changes in ploughing methods.

Finally, some changes in socio-economic system elements are predominantly or exclusively considered environmental change impacts (Table 3.2). These include transportation infrastructure expansion and improvement, effects on human health, and changes in pastures and grasslands, livestock, and cultivated plant species. Impacts on human health were deemed positive due to increased access to health services, but also negative, owing to the increase of vector-borne diseases and the adoption of diets high in processed foods and sugar. The effects on pastures, crops and livestock were complex and steamed from many simultaneous environmental and socio-economic drivers of change. A good example of the complex local discourse about the synergic effect of multiple drivers is one from an old local male farmer: '*It's now that the livestock need to go that far looking for food. Before there was always a "bas-fond*" [lowland fertile areas] *with good grass and herbs for eating, but now bas-fonds are for rice and rivers have become dry. People used to have only few cows, now there are many cows. And not only ours! "Aga"* [transhumant herders] *coming from the North arrive each year with their big herds, they cut down the trees to find fodder for their sheep, but they do not respect anything. They leave the cut branches around the trunks and then big trees are also burn with wildfires*' (Anonymous, February 2020).

Discussion and conclusions

Before discussing the main findings of this work, we start by acknowledging three important limitations. We are aware that 1) due to epistemological differences it is not possible for us to fully assess Bassari knowledge by just interacting with community members for a limited period, 2) by focusing on consensual information, we are ignoring the sociological complexity that determines how knowledge is locally distributed and how environmental change impacts

are differently lived by different socio-demographic groups within the Bassari (e.g., according to gender, age, or social status), and that 3) some of our conclusions are drawn from information collected using different samples. Thus, while not claiming that the results presented here represent Bassari worldviews, but rather our interpretation of them, we believe this representation can help to better understand the impacts of climate change in the context of global change.

Herein, we discuss the main results and debate the existing tensions between scientific and situated and plural understandings of climate change, based on Indigenous, embodied, and experiential knowledges.

Situated perspectives of the global climate change discourse

Bassari were, in general, not very familiar with the term 'climate change'. Most interviewees had either never heard the term or provided definitions that do not match the Western scientific meaning of the concept. These results resemble those among other local communities of the Global South, where the scientific discourse of climate change has barely reached (e.g., Byg, 2009; Fernández-Llamazares et al., 2015), suggesting a lower familiarity with the Western scientific discourse of anthropogenic climate change than in less isolated regions. For example, on the Marshall Islands (Pacific archipelago), 80% of the interviewees had some awareness of the Western scientific notion of climate change (Rudiak-Gould, 2011), and in South England, only 2.9% of respondents were not familiar with the term 'climate change' (Whitmarsh, 2009). Overall, however, it is difficult to draw a conclusion, as there are very few studies explicitly asking about the term 'climate change' in Global South communities (Rudiak-Gould, 2011), and most studies have assessed this familiarity indirectly, by documenting local observations of climate change and its impacts (Marin, 2010; Boillat and Berkes, 2013).

Our results show how access to global climate change knowledge is mediated by gender, age, and level of schooling. Among the Bassari, young well-educated men were more familiar with the Western scientific concept than the rest of the population. Our results also point to wealth as a mediating factor for access to the Western scientific discourse on climate change, as people with access to TV were more aware of the Western scientific discourse around climate change and locally only members of few wealthy households own and have access to TV. Since people's perceptions and understandings of climate change can influence their behaviour toward adaptation and mitigation strategies (Spence et al., 2011; Naess, 2013; Patt and Weber, 2014), differential access to Western scientific climate change knowledge may lead to wealthy young well-educated men being more engaged in the implementation of externally-driven (often top-down) climate change adaptation interventions, and thus to a better representation of their interests and needs compared to those of elders, women, or people without access to schooling. However, we recognize that to build effective adaptation strategies, a focus on the diversity of people's lived experiences and everyday adaptation is crucial (Moulton and Carey, 2023). Drawing from our ethnographic experience, we recognize the pivotal contribution of women and elders to local adaptation. Despite not accessing Western scientific representations, through decades of observation and experimentation other groups have accumulated a wealth of knowledge that ensures that adaptations respond to the needs and desires of local communities and are culturally appropriate and locally feasible.

To the level to which the concept of 'climate change' has made its way to the Bassari communities, it has merged with situated notions of change to form new meanings. Survey participants who stated familiarity with the Western scientific climate change concept did not only refer to changes happening in the atmospheric system, but also referred to climate change information and meanings related to local beliefs and their own traditional representations of the world. Several interviewees stated that 'everything is changing' (referring to changes in the environment, socio-economic system, and way of life). Drawing on situated knowledge and worldviews, some interviewees interpreted climate change as cyclical or as a punishment from super-natural forces for inappropriate behaviour. Thus, our findings agree with those reported for other Indigenous peoples and local communities, showing that situated interpretations of changing climatic conditions have ontological foundations (Boillat and Berkes, 2013; Rosengren, 2018; Scoville-Simonds, 2018). Our research also confirms that local communities do not always absorb the Western scientific climate change discourse despite having access to it (Marin and Berkes, 2013; Fernández-Llamazares et al., 2015), which might be explained by the epistemological gap between the information heard and the one perceived (Hulme, 2009; Marin and Berkes, 2013) and the lack of trust on Western scientific experts (Hmielowski et al., 2014).

Climate change from the lens of the 'everyday'

While Bassari people are not necessarily familiar with the 'climate change' concept, they reported many changes in the atmospheric system, with cascading effects on the physical, biological, and socio-economic systems. Similarly, previous research showed that communities that live in close proximity to the environment have detailed perceptions of weather changes (Green and Raygorodetsky, 2010; Fernández-Llamazares et al., 2015; García-del-Amo, 2021; Reyes-García et al., 2024a). However, by employing a network approach, our results quantitatively assess the relative importance of the various drivers and interactions between climatic and non-climatic changes. This has conceptual and practical implications.

Conceptually, the complex network of drivers and impacts derived from Bassari responses revealed the difficulty of disentangling climate change from the web of material and inmaterial relations that shape people's interactions with their environment (Barnes et al., 2013). Comparably to other Indigenous and local communities (Peloquin and Berkes, 2009; Boillat and Berkes, 2013; García-del-Amo et al., 2024), the Bassari did not see climate change as an isolated phenomenon. Atmospheric changes were inextricably linked to other environmental, social, spiritual, and politico-economic changes that are transforming their life. Interestingly, this blurs the conceptual distinction between climate change impacts and impacts from other socio-economic and environmental drivers, implying that viewing atmospheric changes solely through a climate change lens marginalises and obscures other changes with more immediate significance for people (Ribot, 2014; Nyantakyi-Frimpong and Bezner-Kerr, 2015). Accordingly, current scientific research also underscores the importance of shifting away from disciplinary approaches to climate change research and acknowledges the importance of synergies and trade-offs between climate, environmental, and other underlying socio-economic and cultural changes (Arneth et al., 2020; IPCC and IPBES, 2020).

From a practical perspective, these findings highlight the importance of shifting our focus away from conceptualizing climate change as a biophysical problem that can be tackled in isolation. Understanding 'climatic' drivers as distinct from 'biological', 'physical', and 'socio-economic' drivers leads to the development of climate-change policies that are disconnected from broader trajectories of socio-environmental change, preventing holistic action.

Regarding the local mechanisms of causality and the role of spiritual entities in Bassari explanations of change, Bassari rationales for the causes of local environmental changes combined a mix of material –i.e., changes in elements of the atmospheric, physical, biological, and socio-economic systems– and immaterial causes –i.e., super-natural forces and changes in the value system. Similar elements and mechanisms of causality can be found in traditional Tibetan (Huber and Pedersen, 1997; Byg, 2009), Amazonian (Rosengren, 2018; Reyes-García et al., 2024b), and Andean communities (Boillat and Berkes, 2013; Scoville-Simonds, 2018), where local people also experience, know, and understand many of the complex environmental changes through super-natural forces and spiritual entities. Importantly, in most cases, material and immaterial explanations were linked to local human behaviour, either through direct environmental impacts (e.g., overhunting, deforestation) or indirectly, by influencing super-natural forces (e.g., angering them).

In this regard, Bassari's holistic perspective provides an alternative view of climate change, focusing on the complex synergistic effects between drivers of change, moving beyond the understanding of single elements to the understanding of these elements through their interrelations. Additionally, incorporating perspectives from other knowledge systems necessitates the inclusion of a set of political questions concerning not only whose and what knowledge counts, but also 'what worlds' are permitted to exist (Goldman et al., 2018). While most climate change research has focused on material aspects of adaptation, resilience, and vulnerability, our findings highlight the importance of immaterial aspects (such as values or super-natural forces) in the way Bassari understand and interpret change. This entails that values, beliefs, and symbolic representations of the world absent from Western science need to be taken seriously if we want to foster inter-epistemological and inter-ontological dialogue for a fairer generation of climate knowledge.

Other framings, other responses: epistemological and ontological plurality for justice and change

Global framings of climate change privilege Western science, marginalizing other ways of knowing that are embedded in lived experiences and cultural memories (MacGregor, 2009; Hulme, 2010; Bee et al., 2015). Climate change assessments reproduce power dynamics that stem from colonial histories and their continuity in current capitalist relations (MacGregor, 2009; Hulme and Mahony, 2010; Corbera et al., 2016). The consideration of 'climate change' as a discernible and abstract problem that stems from greenhouse gas emissions happens within a set of values and social relations that are embedded in the status quo of a global and patriarchal capitalist economy and is not free from political implications (Demeritt, 2001; Hulme, 2008; Nightingale et al., 2020).

By prioritizing certain voices in the generation of climate change knowledge, certain interests are prioritized in the design of adaptation and mitigation strategies. For example, the Western scientific construct of climate change has constrained the conception of solutions, leading to the prioritization of 'technical fixes' (e.g., carbon offsetting) that do not challenge the root causes of climate change (Nightingale et al., 2020). As argued by Hulme, instead of addressing why our society is designed around emission intensive production and consumption processes, the global construction of climate change as a physical problem '*readily allows climate change to be appropriated uncritically in support of an expanding range of ideologies … of green colonialism, of the commodification of Nature*' (Hulme, 2008, p. 9). Accordingly, feminist and decolonial scholars argue that efforts to promote climate change adaptation need to ask critical questions about how climate change knowledge is generated and by whom, directly addressing structural social inequalities and social and epistemological justice (Cameron, 2012; Bee et al. 2015; Todd, 2016). Such effort will be fruitless without a deep understanding of how climate change differently affects people on the ground –mediated by gender or other key intersectional dimensions of difference and inequality, whether ethnicity, race, poverty, indigeneity, or coloniality (Buechler and Hanson, 2015).

Contrastingly, when the knowledge systems and views from marginalized voices are acknowledged and inherent power inequalities made explicit, very different research and policy priorities emerge, which can lead to more transformative solutions (Orlove et al., 2023). Our results highlight the complexity of the social, ecological, economic, and cultural relations that mediate how local people experience, interpret, and enact change, contributing with empirical ground to the claims about the need to reframe the way we, as Western scientists, conceptualize and engage with climate change. Our research brings at the forefront people's lived experiences –including emotional, spiritual, and moral dimensions–, pointing to the importance of considering climate change from a relational perspective. Understanding climate change within the broader trajectories of socio-environmental change will encourage acting systemically, beyond technical fixes.

Chapter 4
Agricultural adaptation to multiple stressors in a climate change context. A case study in south-eastern Senegal

This chapter corresponds to book chapter:

Porcuna-Ferrer, A., Guillerminet, T., Klappoth, B., Schlingman, A., 2024. Agricultural adaptation to multiple stressors in a climate change context. A case study in south-eastern Senegal. In: *Routledge Handbook of Climate Change Impacts on Indigenous Peoples and Local Communities*, Chapter 13 (V. Reyes-García, S. Alvarez-Fernandez, P. Benyei, L. Calvet-Mir, D. García-del-Amo, A. B. Junqueira, X. Li, V. Porcher, A. Porcuna-Ferrer, A. Schlingman, R. Soleymani, Eds.). Routledge. https://doi.org/10.4324/9781003356837-18

Ga-syilis (seeding is finished)

On the hillsides, the Bambara groundnut plants are spreading their leaves along the ground while their deep roots pull nutrients from the thin, arid soil.

In a few weeks, all the neighbourhood women will come together to help her in the tedious task of unearthing the nuts.

Abstract

The Bassari country in south-eastern Senegal is undergoing rapid and severe environmental and socio-economic changes steering modifications in the local agricultural system. Drawing on participant observation and 47 semi-structured interviews, this chapter assesses how Bassari farmers experience and respond to multiple environmental, socio-economic, and cultural stressors, including changes in precipitation, increasing crop mortality, pressure on land, integration into market economy, and cultural weakening. Common responses include switching crop species and varieties, shifting plot locations, and increasing the reliance of agriculture on external inputs. The sustainability analysis of those agricultural management changes showed different environmental, social, and economic trade-offs that can limit long-term adaptation options. Differences across gender and wealth regarding who bears most of the costs and who benefits the most were also found, with women and poor households belonging to the most disadvantaged groups. These findings highlight the need to place adaptive strategies in a broad context that, beyond climate change, considers multiple stressors, power dynamics, and farmers' needs and priorities to achieve long-term adaptation.

Key words: Bassari farmers, climate change impacts, intersectionality, multiple drivers, small-scale agriculture, sustainable adaptation, West Africa

Introduction

Smallholder farmers around the world observe inter- and intra-seasonal climate variability and change (Savo et al., 2016; Reyes-García et al., 2019) and use this knowledge to organise their agricultural practices according to local environmental conditions, including climate, soil, and water (Altieri and Nicholls, 2017; Rivera-Ferre et al., 2021). This is also the case for smallholder farmers in West Africa, where episodic droughts have traditionally affected the agricultural rain-fed systems (Nyong et al., 2007) and where scientific evidence predicts increasing risks of crop failures due to rising temperatures and changes in the monsoonal rainfall (Sultan and Gaetani, 2016; Carr et al., 2022). At the same time, smallholder farmers also experience other environmental, socio-economic, cultural, and political changes, including demographic changes and rural-urban migration, increasing integration into global markets, the expansion of infrastructure and technology, and off-farm livelihood activities (Ensor et al., 2019). Moreover, this broad range of multi-scalar, multi-temporal, and interacting stressors have differentiated impacts depending on the context-specific vulnerability of individuals and communities (O'Brien et al., 2004; Bennett et al., 2016). Consequently, although research and policy have primarily addressed the impacts of specific stressors, for example, adaptation to climate change or economic development (Bennett et al., 2016), focusing on only one stressor bears the risk of missing unexpected and negative feedbacks and trade-offs produced by other stressors, thereby undermining environmental, social or economic objectives, maintaining or even increasing vulnerability, and potentially leading to maladaptation (Barnett and O'Neill 2010; Eriksen et al., 2011; Antwi-Agyei et al., 2018).

While climate change research considering multiple stressors and their interactions is on the rise (Räsänen et al., 2016), our understanding of context-specific interactions, interferences, and consequences of responses to climatic and other stressors is still limited (Ensor et al., 2019). Importantly, specific responses might have context- and group-specific impacts, for example, if the response favours some, but result in additional efforts, costs, or even negative outcomes for others (Segnon et al., 2021). Eriksen et al. (2011) argue that assessing responses from a sustainability perspective entails considering the interdependencies between environmental, social, and economic objectives to understand the vulnerability context in which adaptive responses are framed. Therefore, a thorough multi-stressor and multi-facet analysis that assess environmental, social, and economic implications of adaptation for different social groups is needed to anticipate trade-offs, avoid maladaptation, and foster long-term adaptation.

In response to this need, here we examine smallholder farmers' responses to multiple stressors in the context of climate change. Our specific objectives are to explore (i) the main changes in local agricultural practices, (ii) the drivers of those changes (also named 'stressors'), and (iii) associated costs, benefits, and trade-offs. In our analysis, we pay attention to the specific implications that changes in agricultural practices have for the different sustainability spheres (i.e., environmental, social, and economic) and social groups (i.e., across gender and wealth). Based on vulnerability and adaptation literature dealing with multiple stressors (e.g., O'Brien et al., 2004; Tschakert, 2007; McDowell and Hess, 2012) and intersectionality (Kaijser and Kronsell, 2014; Ravera et al., 2016a), our discussion enriches the debate on which of the changes in agricultural management practices, beyond bringing climate change resilience, also contribute to social justice, environmental integrity, and economically viable livelihoods (Eriksen et al., 2011).

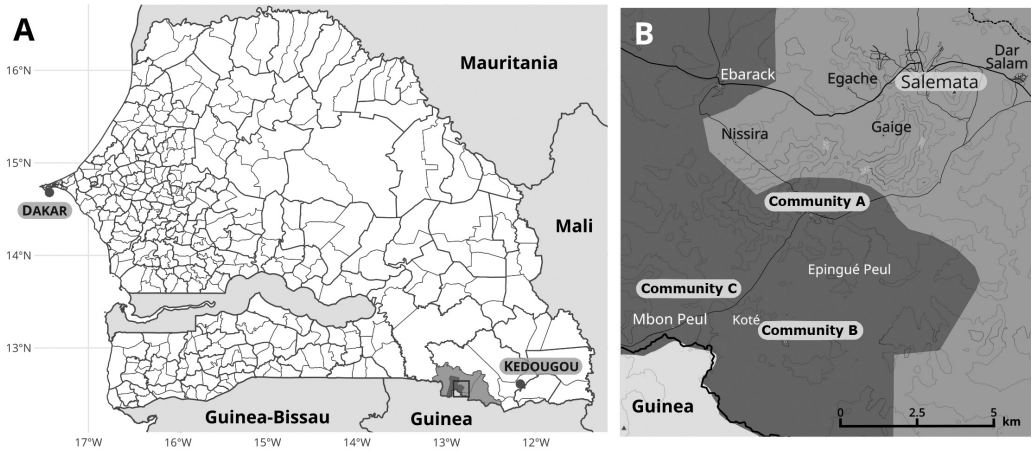

Figure 4.1: A) Map placing the study area within Senegal. The clear and dark grey polygons respectively represent the department of Salemata and the commune where the case-study communities are located. B) Case-study communities.

The Bassari

We conducted research among the Bassari, located in the Kédougou region in south-eastern Senegal (Figure 4.1). The region is characterised by low altitude (approx. 80-380 m a.s.l.), tropical dry or savanna climate, annual mean temperatures around 28 °C, and a unimodal rainy season from approx. June to October dominated by the West African monsoon system (Sultan and Janicot, 2003; ANACIM, 2020).

With a wetter climate than the northern regions, south-eastern Senegal was less affected by the Sahel droughts of the 1970s than most Senegalese regions. And although there are important interannual rainfall variations, historical trends show a partial recovery of the lack of precipitation from the 90s onwards. Nonetheless, future climate predictions for the West African region indicate a trend towards higher temperatures and shorter rainy seasons (Sultan and Gaetani, 2016).

Only 10 % of the Bassari region's surface is cultivated and the remaining area preserves large forests and bushlands that are home to many wild flora and fauna. However, population density, currently below 20 inhabitants/km^2, is on the rise resulting in a gradual disappearance of forests and bushlands in favour of cultivated fields (UNESCO, 2011). The Kédougou area hosts several ethnic minorities (UNESCO, 2011), among which we worked with the Bassari.

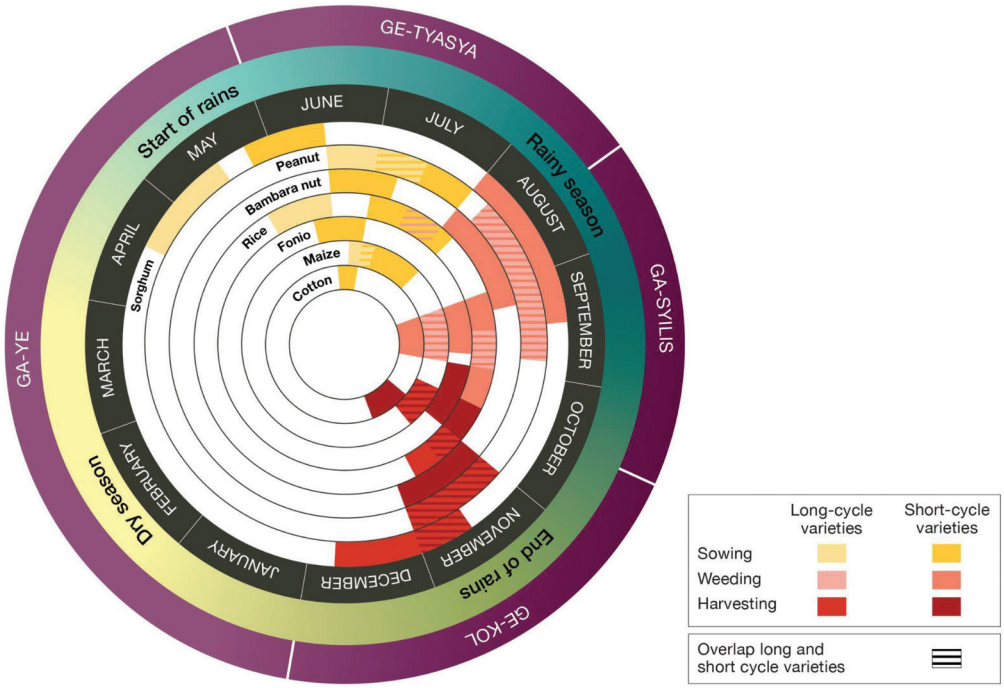

Figure 4.2: Bassari agricultural seasonal calendar. The Bassari identify four seasons: (1) '*Ga-Ye*' (i.e., 'time to rest') corresponding to the dry season, during which agricultural work is paused; (2) '*Ge-Tyasya*' (i.e., 'time to seed') which refers to the onset of the rainy season; (3) '*Ga-Syilis*' (i.e., 'seeding is finished'), or the core of the rainy season and the main crop growing period; and (4) '*Ge-Kol*' (i.e., 'time to harvest'), which refers to the harvest period and corresponds to the end of the rainy season.

Nowadays, the Bassari mostly rely on small-scale agriculture, which is highly dependent on the use of communal land and shared labour (Nolan, 1986). The importance of agriculture in Bassari life is reflected in the naming of the seasons (Figure 4.2). Agricultural activity is concentrated in the short rainy season. During the dry season, some women practice small-scale horticulture production (e.g., onions, tomatoes, salads, cabbages), while men generally engage in off-farm employment, including construction work, wage labour, art craft, tourism, and seasonal migration.

Bassari farming system is organised into four agroecological field types, cultivated with different crop species and managed distinctly (Table 4.1). On average, households cultivate a mean area of 2.1 ha (min: 0.4 ha; max: 9.5 ha). The typical cropping pattern of Bassari smallholders is the rotation of cereals (sorghum, *Sorghum bicolor*; maize, *Zea mays*; fonio, *Digitaria exilis*) and legumes (peanut, *Arachis hypogaea;* Bambara groundnut, *Vigna subterranea*). In the plains, the Bassari also cultivate rice (*Oryza sativa*), which is not subject to crop rotation, and small-scale horticulture. The main cash crop is cotton (*Gossypium hirsutum*), cultivated as part of a farming contract system.

Table 4.1: Local taxonomy of field types and the main crops and management practices associated.

Field type	Description	Cultivation season	Main food crops	Crop rotation	Fertilisation	Irrigation
'*Oxenga*'	Soils poor in organic matter (often shallow), mostly on hilly terrains	Rainy season (June-October)	Sorghum, peanut, bambara groundnut, cotton, fonio, (maize)	Yes	Slash-and-burn fallow system, few chemical inputs (mostly used in cotton)	No irrigation, rain-fed
'*Eden*'	Soils rich in organic matter with a fine texture, mostly located in the plains or valleys and near the streams	Rainy season (June-October)	Rice, maize	No	Use of chemical inputs	No irrigation, rain-fed
		Rainy season (June-October)	Tubercules: taro, yam	No	Use of biological fertilisation –e.g. tree leaves and branches, and ashes	No irrigation, rain-fed
		Dry season (November/ December-May)	Horticulture: tomato, salad, aubergine, carrot, onion, etc.	No	Use of both, chemical and biological fertiliser (mostly NPK and/or cow dung)	Irrigation, well water
'*Enam*'	Soils surrounding the households, usually rich in organic matter	All year	Maize, fruit trees, spices, vegetables	No	Fertilised by the livestock kept in the household	No or only punctual irrigation

Research methods

Data were collected between November 2019 and March 2020, and benefited from the authors' long presence in the community –16 months in total, between 2019 and 2021– and the support of four Bassari research assistants. Before starting data collection, we received ethical approval from the Autonomous University of Barcelona (CEEAH 4903) and obtained the permits to conduct the research from the relevant village authorities.

Sampling and data collection were conducted according to the criteria described in the Local Indicator of Climate Change Impact (LICCI) protocol (Reyes-García et al., 2023), summarised below.

Sampling

We worked in three villages in the Bassari country, with 109, 55, and 24 households, respectively. To select participants for semi-structured interviews, we used 'quota sampling' aiming at capturing the diversity of knowledge across gender, age, and wealth. In total, we interviewed 34 men and 13 women from different households, the main social and economic structuring unit in the site. We have a lower sample of women because they were generally less available for interviews; 10 participants were < 40 years old, 17 were between 40 and 60 years old, and 20 were > 60 years old. Household wealth was defined with the help of the research assistants and based on local conceptions. Research assistants classed households into three groups taking into account herd size, polygamy, cultivated area, and possession of material assets: low resources (~40 % of households), intermediate (~50 % of households), and wealthy (~10 % of households).

Data collection and analysis

To understand how multiple stressors affect the local agricultural system, we first asked interviewees to describe changes in on-farm management practices that they have observed since their youth, including changes in the type of cultivated crop species and varieties, changes in management practices in the different stages of the cultivation cycle –including seed selection and acquisition, land preparation, sowing, cultivation, harvesting–, and changes in post-harvest treatment, storage, and commercialization. For each reported change in local agricultural management practices, we asked the interviewee to explain what had driven such changes.

We additionally explored positive and negative experiences associated with each change in agricultural management practices and recorded the age, gender, and wealth group of each interviewee to assess benefits, costs, and trade-offs for different social groups.

Before presenting our main results, we acknowledge two main limitations of this work. First, our data were not collected to systematically analyse how power relations shape farmers' adaptation options. However, farmers' explanations of the costs, benefits, and trade-offs of different agricultural management practices, together with our understanding of the site dynamics, allowed us to identify that farmers' responses to multiple drivers can simultaneously lead to positive changes for some groups and negative consequences for others. Second, the limited time frame of our research makes it difficult to fully understand or evaluate the long-term outcomes of farmers' strategies. However, results from our empirical work shed light on the complexity of local farmers' adaptation to multiple drivers.

Results

Bassari farmers have adapted their agricultural practices in response to environmental and socio-economic drivers including: (1) climatic (i.e., declining crop yields due to changes in precipitation, temperature, and fog), (2) demographic (i.e., higher land pressure due to population increase and labour shortages due to migration), (3) economic (i.e., increasing monetization of the livelihood system through market integration, which caused higher cash dependency, higher reliance in off-farm activities, and trends towards economic efficiency), (4) social (i.e., increasing influence of NGOs and extension services, and decrease in community's social capital such as communal work and reciprocity), and (5) cultural (i.e., weakening of traditions and cultural norms and changing dietary preferences). These drivers have generated impacts in the local farming system and shaped changes in agricultural management practices, including changes in crop species and varieties, changes in seed management, and changes in soil cultivation practices (see Figures 4.3 and 4.4). Agricultural management changes come along with certain benefits, costs, and trade-offs for different sustainability spheres and social groups, as we next outline.

Adoption of new crop species

The most prominent change in agricultural management practices refers to the adoption of new crop species. Traditional Bassari staple crops were sorghum, fonio, and Bambara groundnut. Introduced staple crops include rice, maize and peanut. The adoption of new crops and in particular rice and maize (for subsistence) and cotton and horticulture (for sale) were common changes mentioned by farmers. The introduction and expansion of horticulture (2000s) and cotton (1970s) is relatively recent. Rice (19th century) and maize (1930s) have been in the Bassari farming system for a longer time, although their cultivation has experienced a dramatic increase in the last decades. As a direct consequence of adopting new crops, farmers have reduced or even abandoned the cultivation of traditional crops. Due to the higher water and soil fertility requirements of maize, rice, and horticulture, the switch from traditional to new crops also entailed a change in the cultivation location, from hilly areas to the plains.

Drivers

The adoption of maize and rice involved a mix of economic, social, and cultural reasons. Farmers justified the adoption of maize and rice arguing that these crops provide high yields and require less labour than traditional crops. Among the Bassari, agricultural labour is becoming a limiting factor due to off-farm migration in search for jobs that provide cash income, the decrease in the number of common agricultural working days, and the increase of children schooling (who traditionally were an important help in the fields). Moreover, development projects –which intensified their presence in the Bassari area in the recent decades– play a key role in the introduction of new high-yielding rice and maize varieties. Dietary preference for maize and rice have also contributed to the adoption of these crops.

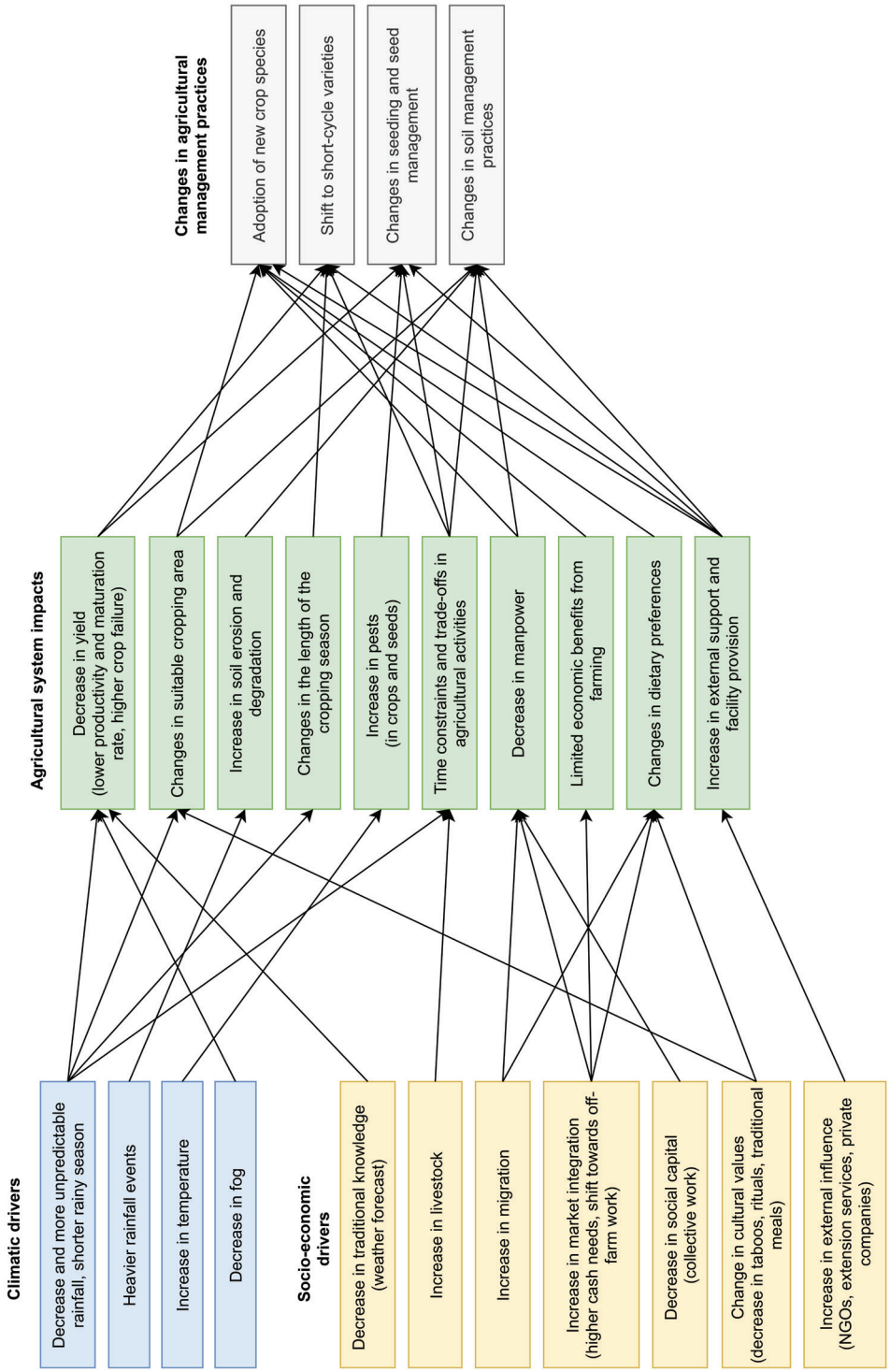

Figure 4.3: Conceptual map showing multiple drivers and impacts on the Bassari agricultural system and resulting changes in agricultural management practices.

Farmers mentioned mainly economic and social considerations for the adoption of cotton and horticulture. Increased cash needs and the role of external agents –NGOs for the introduction of horticulture and a state enterprise (later privatised) for cotton– were mentioned as the main drivers of cotton and horticulture adoption. Nowadays, cotton is the main source of agricultural income and all interviewed farmers referred to the need to cover the rising costs of living –for example, children's schooling, food, and access to health services–, as well as the rising demands for commericial goods like smartphones or motorbikes. In the discussions with women farmers, they mentioned that horticulture has become increasingly popular because the facilities provided by NGOs –for example, seeds and materials for fencing– make the commercialization of vegetables profitable. None of the farmers interviewed mentioned that their decisions to adopt new crop species reflect a response to climatic stress.

Costs, benefits, and trade-offs

The need to change the planting location was the most frequently mentioned trade-off derived from rice and maize adoption. Given their water requirements, rice and maize cannot be cultivated in the hills, like Bassari traditional staple crops. This shift aggravates land scarcity and promotes unequal land access, also reinforced by population growth and cultural changes in the land tenure system, which has shifted from commonly managed user rights defined by kin groups to private property. The cultivation of maize and rice lowers the value of hilly land and intensifies land pressure in the plains. Bassari recognised that '*Now the fields are smaller, and it is difficult to find land in the plains. (...) We are many more people!*' (Anonymous, female farmer, February 2020). In the past, higher-status and wealthier households preferred hilly land. The less desirable plains –characterised by a dense vegetation, soils non-suitable for traditional crops, and protected by cultural taboos– were only used by households settled in the village margins or by ethnic groups who arrived later to the area (e.g., Fula). Nowadays, only those households who traditionally inhabited or cultivated the plains, or wealthy households who can use their financial and social status to borrow land from others, can cultivate the plains and therefore adopt new and higher-yielding crop species. Interviewees expressed additional concern about the expansion of agriculture into sacred and protected areas like the river basins with dense riparian forests, where, in the past, taboos banned cutting the trees.

Farmers claimed that rice and maize have high water requirements that make them generally more susceptible to dry spells than Bassari traditional crops. However, they also mentioned this drawback to be compensated through the higher water retention capacity of the soils in the plains, which reduces the risk of water stress that occurs in hilly areas. Farmers also referred to the high needs for fertilisers and pesticides as a trade-off for the adoption of rice and maize. According to farmers, the growing demands on land limit the use of traditional crop rotation and fallow periods, which leads to declining soil fertility and increasing soil degradation. Consequently, as fields in the plains are rarely rotated or left fallow and as the new crops have high soil nutrient requirements, regular fertilisation is needed. Some farmers also noticed that the reduction of fallow periods and the lower quality of purchased seeds leads to a greater presence of pests, which requires the application of more pesticides.

For horticulture, farmers reported problems with water scarcity and conflicting interests between household consumption and irrigation needs. This problem was mainly presented by women, who

also saw an increase in their work burden due to water scarcity: '*Before sunrise is when there is more water. If you want to irrigate your crops, you need to wake up very early*' (Anonymous, female farmer, March 2020). Horticultural activities also generate disparities, since only some neighbourhoods have access to land suitable for horticulture. As a woman farmer explained: '*I would cultivate tomatoes, onions, and lettuce if I had a place*' (Anonymous, female farmer, March 2020).

Cotton has high requirements for fertilisers and pesticides, representing a form of intensified agriculture that demands more labour to fumigate and fertilise plots, and additional cash to purchase external inputs, thereby creating higher market dependence. Cotton is mostly cultivated by men, who also control the income from cotton sales, which is often used to buy status items (e.g., smartphone, motorbike) and –according to women interviewed– not invested in family expenditures. Hence, the shift towards cotton cultivation had negative implications for women's control over household income and decision-making.

During the 'cotton boom' in the early 2000s, many families almost entirely switched to cotton, reducing the area dedicated to self-consumption. However, in the face of yield failure, low cotton market prices, or unexpected cash needs (e.g., in case of illness), these households became food insecure. Nowadays, most households keep a balance between cotton and subsistence crops. Still, big shares of land and labour are put into cotton cultivation and the proportion devoted to subsistence crops has declined. To compensate for the lack of cultivated subsistence crops, women search for alternative strategies to ensure household food security (e.g., through off-farm work), while at the same time supporting cotton cultivation. In other words, cotton cultivation competes with subsistence crops for land and labour, thereby challenging family food needs and increasing women's work burden.

Shift to short-cycle varieties

The shift from long- to short-cycle varieties was a change commonly mentioned by Bassari farmers and affecting maize, rice, peanut, and fonio, for which short-cycle varieties are available. For sorghum, farmers mentioned adopting a medium-cycle variety. No short- or medium-cycle varieties are available for Bambara groundnut.

Drivers

Farmers reported climatic stressors, scheduling conflicts with other activities (i.e., livestock rearing and off-farm work) and external influences as the main drivers of the shift to short-cycle varieties. Farmers considered traditional long-cycle varieties vulnerable to the changing climate, especially regarding unpredictable rainfall, shorter rainy seasons, and more frequent dry spells. They also explained that in the past, the rainy season lasted from May to November and allowed the cultivation of long-cycle crops, whereas nowadays the rain lasts from mid-June to beginning October and only allows for short-cycle crops and varieties. Respondents also mentioned that in the past communities relied on fog at the end of the rainy season for the final maturation of long-cycle crops, like certain sorghum varieties. Nowadays, however, fog is scarce and too unstable to ensure the final maturation of long-cycle varieties.

Farmers also referred to trade-offs between long-cycle varieties and livestock rearing. Free-ranging livestock is kept in communal land during the dry season and at the end of the growing season, when crops are harvested. This practice increases the risk of crop damage by grazing livestock, especially for long-cycle varieties. Farmers also mentioned that the shorter growing cycles fit better with the seasonality of off-farm jobs.

Finally, farmers mentioned that the adoption of short-cycle rice, maize, and peanut varieties was supported and subsidised by NGOs and government development programs, which increases profits by reducing investment costs.

Costs, benefits, and trade-offs

Farmers attributed positive traits to some of the traditional long-cycle varieties that are being lost, which were perceived as more productive, less vulnerable to pests and weeds, more robust to low soil fertility, more durable when stored, and more tasty and nutritious.

Changes in seeding and seed management

Farmers reported three main changes regarding seeding and seed management: (1) changing seed storage techniques by applying chemical pesticides, especially for legume seeds; (2) shifting the planting calendar from the beginning of June to the beginning of July; and (3) re-seeding more often due to the increasing difficulty to find the right moment to seed.

Drivers

Farmers argued that changes in seed storage practices were a response to higher seed degradation from pest infestations due to temperature increase. Pest infestations particularly affected legume crops like peanut and Bambara groundnut. As one farmer explained: '*There are too many insects in the seeds. Before you could store them from one cropping season to the next. Nowadays if you leave it, at the moment of seeding you will just find powder*' (Anonymous, female farmer, January 2020). They acknowledged that the use of chemical pesticides for seed storage was initially promoted by NGOs, who used to distribute chemical pesticides for free, although now farmers have to buy them.

Farmers explained the shift in planting schedules as a response to the delayed and shorter rainy season and the higher frequency of dry spells. Farmers described that they cannot seed when the first rain arrives, as they used to do, because no other rains follow, and the germinated seeds dry out: '*Sometimes you organise a big common agricultural working day hoping that the first rains will follow soon, but if the rain does not arrive, you lose everything*' (Anonymous, male farmer, January 2020). At the same time, the shorter rainy season forces farmers to harvest earlier, compared to the past. Seeding later but harvesting earlier makes shifting to short-cycle varieties necessary. Otherwise, crops do not reach maturity before the end of the rainy season, resulting in significant yield losses. As one middle-age male farmer said: '*If you seed too early, you risk that the seeds will dry out in the field; but if you seed too late, crops will not reach maturity*' (Anonymous, male farmer, February 2020).

Figure 4.4: Examples of changes in Bassari agricultural practices as response to different impacts on the agricultural system.

Unpredictable rainfall, the decreased reliability of traditional indicators of weather forecast, and the loss of weather forecasting knowledge were all considered factors increasing the difficulty to identify the right time to seed.

Costs, benefits, and trade-offs

Additional costs, including risks, were mentioned in relation to changes in seed storage methods. Since NGOs do not freely distribute chemical pesticides anymore, farmers with less economic resources cannot afford buying them and continue to apply traditional forms of seed storage (e.g., mixing seeds with ashes and certain wild plants that keep insects away). Moreover, some farmers complained about the toxic effects of chemical pesticides on human health and refused to use them.

Altogether, there are more costs in accessing and storing seeds, including an increased risk of seed losses during storage and a large dependency on external seed sources (e.g., markets, NGOs). For example, several women farmers mentioned incidents of spurious seeds or of seeds that did not correspond to the announced crop variety with seeds obtained at the market. Some farmers also attributed pest infestations to the purchase of seeds from markets or unreliable sources.

Changes in soil management practices

Farmers mentioned two main changes related to soil management practices: the shift from the hand hoe to the oxen-plough and the construction of stone-bands and half-terraces on fields.

Drivers

When asked about the reasons for shifting from the hand hoe to the oxen-plough, most farmers referred first to reduced workload and lower labour demand. The oxen-plough was also related to the increased cultivation in the plains, which allows more efficient ways of ploughing the soil. Several farmers additionally mentioned that owning an oxen-plough was beneficial under current unpredictable rainfall conditions, since the oxen-plough allows quick soil preparation and seeding, thereby offering farmers more flexibility, compared to the hand-hoe.

The main reason for farmers to place stone-bands or trunks along the contours of hilly fields, or building half-terraces, was the prevention of soil erosion in response to more frequent flash floods.

Both measures were introduced by NGOs and development projects, which made oxen-plough available and trained farmers on the use of stone-bands and terraces on hilly terrains.

Costs, benefits, and trade-offs

Farmers mentioned that the benefits of the oxen-plough are not accessible to everybody. For example, a middle-aged woman explained: '*If you own an oxen-plough, as soon as the rain comes, you seed. But if you do not own it, then you will have problems, you need to wait for your turn* [the oxen-plough is usually shared in exchange for work, some people also rent it] *and sometimes when they come to plough your field, it is too late*' (Anonymous, female farmer, February 2020).

Regarding the construction of stone-bands or terraces on hilly fields, interviewed farmers agreed that labour and time constraints were the main factors that hindered the wider implementation of this practice.

Discussion

We structure the discussion around the three main findings: (a) farmers adapt their agricultural management practices in response to multiple stressors; (b) changes in agricultural management practices imply trade-offs among environmental, social, and economic factors; and (c) the distribution of costs and benefits arising from adaptation varies across social groups.

Changes in agricultural management practices are driven by multiple stressors

Changes in farming practices such as changing crop species and varieties and market-based horticulture have been documented and conceptualised as climate change adaptation strategies in Senegal (Mertz et al., 2009; Ruggieri et al., 2021) and the world (Schlingmann et al., 2021). However, the predominant focus on climate change as a main driver of change masks the socio-political root causes of household and individual vulnerability (Ribot, 2014). As our case study shows, farmers do not only switch to shorter-cycle varieties due to the shortening of the cropping season, but also due to labour constraints, higher yields, and dietary changes. In this regard, drivers of change in Bassari agricultural management practices are multifactorial, with socio-economic, political, and cultural stressors being as salient as climate change in guiding farmers' decisions. Other studies have also documented that climate change is not necessarily the main or unique stressor driving livelihood changes in local communities (Nyantakyi-Frimpong and Bezner-Kerr, 2015). Multiple, compounding, interacting, and intertwined stressors that are deeply entangled in the integration of smallholder farmers' communities into globalisation and capitalist economies –such as new economic opportunities and cash needs, population growth, and the weakening of cultural norms and traditions– strongly determine community's and households' vulnerability and are perceived to be equally or even more relevant than climatic stressors (Ensor et al., 2019).

Still, the fact that non-climatic challenges are currently perceived as more significant for local farmers does not downplay the need for adaptation to the mounting threats of climate change. In the light of our findings and in line with McDowell and Hess (2012) and Izquierdo and Schlingmann (2024), we argue for the importance of designing climate change adaptation interventions that allow farmers to better confront multiple stressors according to their own needs and priorities.

Costs and benefits of changes in agricultural management practices result in trade-offs between environmental, social, and economic factors

Our results show that changes in Bassari agricultural management practices entail different costs under the different sustainability spheres, which can have contradicting and sometimes unwanted trade-offs for local communities, leading to maladaptive outcomes and increased vulnerability.

A response that is beneficial with respect to one stressor might be insufficient or ineffective, or even conflict with addressing other stressors (Bennett et al., 2016). For example, a response to new economic conditions does not necessarily increase climate resilience and a response to climatic stressors is not necessarily economically beneficial or viable, as it happens when there is a mismatch between climate-compatible crops and market-driven demand for those crops (O'Brien et al., 2004). Our case study illustrates trade-offs between environmental, social, and economic costs that can lead to maladaptive outcomes. For example, the increase of marketable cotton, maize, and rice cultivation (short-term economic benefits) contributes to the abandonment of traditional crops, like sorghum, fonio, or Bambara groundnut, which are generally better adapted to local environmental conditions and droughts (environmental costs) (Hadebe et al., 2017; Mayes et al., 2019; Abrouk et al., 2020). Switching to horticultural cash-crops can improve households' income (economic benefits), but the additional need for irrigation can put stress on water resources (environmental costs) and potentially lead to conflicts because of different demands and interests (social costs) (Antwi-Agyei et al., 2018; Akinyi et al., 2021). Similarly, an increasing dependence on improved drought-resistant short-cycle crop seeds (environmental benefits), increases households' vulnerability to market uncertainties and price fluctuations (economic costs) (Galappaththi and Schlingmann, 2023). Introduced crops also tend to be more susceptible to pests, resulting in frequent application of chemical pesticides with risks to human health (social costs), environmental degradation (environmental costs), and additional cash needs (economic costs) (Dhakal and Kattel, 2019; Akinyi et al., 2021). Growing a mixture of traditional crops would allow households to have effective strategies against food insecurity in the face of reduced landholdings, changing rainfall patterns, and decreased soil fertility (environmental and social benefits). However, growing traditional crops implies high labour requirements and low income, since they are not yet integrated into market logics (economic costs) (Galappaththi and Schlingmann, 2023).

In this regard, adaptation to the most impacting stressors in the short term can limit long-term adaptation options and climate resilience when they deliver maladaptive outcomes for one of the different sustainability spheres (McDowell and Hess, 2012; Porcuna-Ferrer et al., 2024a). Only when farmers' responses reduce harm in all three spheres, they can be considered sustainable adaptation (Eriksen et al., 2011; Wilson, 2014). This emphasises the need for research and policy to design and evaluate climate change adaptation options by considering the trade-offs between environmental, social, and economic spheres in order to avoid lock-ins that could increase future climate vulnerabilities.

Costs and benefits of changes in agricultural management practices are unequally distributed across social groups

Another important finding of our research is that changes in agricultural management practices entail different costs, benefits, and trade-offs for different social groups, with the least vulnerable bearing the benefits and the most vulnerable (i.e., women and poor households) often bearing the costs. Gender or access to financial, physical, and natural capitals define who in the community or within a household can implement and benefit from certain changes in agricultural management practices. This is specifically the case of the usage of oxen ploughing, cotton cultivation, horticulture, and the relocation of fields to the plains, which increased the benefits of some groups and the costs of others. For example, in the study area, the adoption of the oxen-plough mostly benefited a very small number of wealthy households with direct access to an oxen-plough. This is in line with other studies

that highlight how unequal access to physical and natural assets affects the scheduling of seasonal agricultural activities of poor households (Roncoli et al., 2001). Regarding cotton cultivation, underlying inequities between men and women in cash access and decision-making influenced their capacity to benefit from cotton expansion, which points to the importance of intra-household power dynamics to access adaptation options (see also Ravera et al., 2016a). Moreover, our results add empirical evidence to the literature that argues that the implementation of certain adaptation strategies, besides reinforcing pre-existing inequalities, can also entail the renegotiation of local power relations (Ravera et al., 2016b). This is the case for horticulture and the relocation of agricultural fields to the valleys where differential land access between households defined their adaptive capacity and thereby created new inequalities. For example, market-oriented horticulture of water-demanding vegetables enhanced the climatic sensitivity of women with limited access to land with wells, as confirmed by other studies (e.g., Labeyrie et al., 2021b).

While the analysis of how the intersection of power and social relations shapes adaptation processes receives increasing scholarly attention (Kaijser and Kronsell, 2014; Ravera et al., 2016a), it still remains largely unexplored for rural farming communities of the Global South –see Onta and Resurrección (2011) and Carr and Thomson (2014) for exceptions. Results from our case study reinforce the notion that power-dynamics largely depend on context-specific socio-economic and biophysical characteristics that either catalyse or constraint farmers' adaptation options (Carr and Thompson, 2014; Kaijser and Kronsell, 2014; Thompson-Hall et al., 2016). Our results also offer empirical insights into how power dynamics are not fixed but changing under new conditions as people adapt to change. These findings thus make clear that adaptation is not an homogenous process that equally benefits all community members and highlight the importance of considering how multiple dimensions of social identity interact and jointly influence how farmers differently experience, manage, and benefit from changes in agricultural practices (Ravera et al., 2016b). We argue for the need for grounded power-sensitive approaches as a first step before any intervention to foster climate change adaptation at the local level.

Conclusion

Bassari agricultural system and management practices are impacted and steered by various stressors, from climate change to increased land-scarcity, increasing monetization of the economic system, and changes in social capital and cultural norms. Bassari farmers are responding to those multiple and simultaneously occurring changes by modifying their farming practices. The analysis of changes in agricultural management practices from a 'sustainable adaptation' perspective (*sensu* Eriksen et al., 2011) and using an intersectional approach shows that not every change can be considered a sustainable adaptation, nor equally beneficial for all social groups.

From these results, we derive two important conclusions. First, changes in agricultural management practices have multiple trade-offs derived from different environmental, social, and economic costs: what in the short-term seems a good adaptation option to one stressor can in fact erode access to important assets and therefore, lower farmers' future adaptive capacity to respond to other stressors. An overemphasis of policies on market demand as the only or most important stressor affecting sub-

sistence farmers may deviate attention from other equally important stressors (e.g., climate change), overall resulting in increased vulnerability. Second, our results offer new empirical evidence about the underlying contextualised factors that shape response options and outcomes for different social groups. The changes in agricultural management practices implemented by Bassari farmers led to benefits for some groups, but to costs to others, increasing the burden of the most vulnerable (i.e., women and poor households). We argue that it is important to include power and gender analysis as a first step for any intervention aiming at fostering local adaptation.

Our arguments aim to put the threats posed by climate change on agricultural systems in the context of the multiple cultural, environmental, political, and economic dynamics that intersect with them shaping the life and practices of smallholder farmers of the Global South. Understanding farmers' adaptation processes in their broader context, paying attention to additional risks, unequally distributed costs, and long-term trade-offs allows us to understand climate change impacts within the lived experiences of local communities, and help design adaptation strategies that efficiently reduce vulnerability to climate change and other impacts. Climate change policies should prioritise long-term and multi-beneficial adaptation measures, while avoiding responses that reproduce existing inequalities and undermine farmers' long-term resilience. Adaptation policies should be designed from a holistic intersectional approach that considers multiple-stressors, trade-offs, and power-dynamics.

Chapter 5
Drought-tolerant indigenous crops decline in the face of climate change: A political agroecology account from south-eastern Senegal

This chapter corresponds to the article:

Porcuna-Ferrer, A., Calvet-Mir, L., Faye, N. F., Klappoth, B., Victoria Reyes-García, V., Labeyrie, V., 2024. Drought-tolerant indigenous crops decline in the face of climate change: A political agroecology account from south-eastern Senegal. *Journal of Rural Studies*, 105, 103163. https://doi.org/10.1016/j.jrurstud.2023.103163

Ge-kol (time to harvest)

Tomorrow, when the truck from the cotton company
arrives, it will be celebration time. The whole
neighbourhood will be there. The company representatives,
all men, will get down off the truck and formally
greet local farmer representatives, all men.

Bale by bale, they will start weighing the treasure. Everyone
will hold their breath as the final weight is announced.
Afterwards, loud whispers and relief. '*Thank God this season
has been better than the last one!'* The farmers' faces will
brighten up as the chief company representative pulls out
a wad of bills from his pocket and counts them slowly.
Young men will load the piles of cotton onto the truck.

Nearby, from a small hill, in the shade, the elders will observe
the scene. Is it sadness, or do I only imagine what I think I
read in their eyes as the truck, to the cheers of the youngest,
zooms off into the horizon leaving a great cloud of dust?

Abstract

In south-eastern Senegal, Bassari farmers have historically cultivated and consumed a wide diversity of varieties of sorghum, fonio, and Bambara groundnut, most of which thrive in poor soils, are nutritious, and withstand drought. These crops are now on the verge of disappearance from the fields of the Bassari despite their potential fit in the predicted drier climate in the area. To understand why, we explore the intertwining between the local dynamics of crop diversity and socio-economic changes at local, national, and regional scales. We draw upon the critical reading of secondary sources and field data, analyzed through the lens of political agroecology. The abandonment of traditional Bassari crops can be explained by government and international policies that interact with cultural trends and household-level factors. Colonial and post-colonial agricultural policies and research priorities have promoted the expansion of exotic crops with market value or high yield potential (e.g., peanut, cotton, rice, horticultural crops), failing to value indigenous crop diversity. These policies, together with market forces and historical legacies, have intersected with outmigration, dietary changes, decreases in community social capital, and gender-dynamics, favouring the switch from drought-tolerant traditional crops to more water-demanding exotic crops. We then consider what the interplay between social dynamics and crop diversity means under climate change. Our results suggest that current trends in crop diversity might threaten climate resilience in the long-term. Drawing on political agroecology, we discuss potential avenues to support the capacity of Bassari farmers to practice agriculture in a drier climate. We argue that in order to increase the climate resilience of smallholder farmers it is necessary not only to consider the cross-scale processes and multiple dimensions of power that affect crop diversity but also to reconsider research and policy priorities in favour of drought-tolerant indigenous crops.

Key words: agrobiodiversity, diversification, farmers' decision-making, Indigenous and local knowledge, neglected and underutilized species, political ecology, resilience,West Africa

Contentious narratives: the role of agrobiodiversity in smallholder farmers' resilience to climate change

Small-scale rain-fed farming is the main form of agriculture practiced in West Africa and in the world and plays a central role in global food security and agrobiodiversity[1] conservation (Lowder et al., 2016; Ricciardi et al., 2018). Climate scientists predict that West African agriculture will experience a dramatic increase in climate variability and intensity of droughts in the future, which in some regions could compromise crop yields and food security (Sultan and Gaetani, 2016).

Traditionally, selecting, diversifying, and modifying crop species and variety portfolios have been important strategies for smallholder farmers to adjust to socio-economic and environmental shocks and shifts (Vigouroux et al., 2011; Leclerc et al., 2013; Ruggieri et al., 2021). However, the unprecedented rate and uncertainty of future climate change impacts poses the question of whether the crop and variety portfolios and the crop diversity access mechanisms that smallholder farmers currently have will be enough to cope and adapt to climate change (McGuire and Sperling, 2013; Labeyrie et al., 2021a). There is a certain consensus that supporting farmers' access to and use of crop diversity is crucial in addressing climate change challenges in agricultural landscapes (Lin, 2011; van Etten, 2019; Pörtner et al., 2021), yet disagreements exist regarding the specific actions and strategies that should be implemented.

The debate on how to support smallholder farms' resilience is open to a variety of competing narratives, each suggesting different pathways to ensure farmers' harvest and secure food supplies despite climate uncertainties, including drought (Mockshell and Birner, 2020). A major point of disagreement revolves around whether climate resilience will be better enhanced by promoting the adoption of research varieties from a limited number of climate-adapted crops, bred for efficiency and homogeneity of traits (from now on 'mainstream development' narrative), or by embracing the heterogeneous populations of inter- and intra-specific diversity that smallholder farmers have selected, managed, and cultivated over generations to adapt to place-based cultural and environmental specificities (from now on 'agrobiodiversity-based' narrative).

In West Africa, policies and regulatory frameworks have been historically geared towards the mainstream development narrative, favouring highly uniform agricultural systems, centred around few varieties of a handful of crop species in high-input production systems and centralized top-down models of seed and information dissemination. Two well-known examples of policies and interventions rooted in this narrative are the 'peanut boom' during French colonial rule (Bernards, 2019) or the 'New Green Revolution for Africa' in recent years (Patel, 2013; Bellwood-Howard and Ripoll, 2020), both aiming at intensifying and specializing agricultural production to gain access to global markets. Critical research, however, questions who benefits and who loses from such policies and interventions. At local-level,

[1] Here, agrobiodiversity refers to the species- and variety-level diversity of food plants.

these mainstream development approaches have systematically ignored farmers' traditional crops and landraces, often resulting in smallholder farmers' growing crops not suitable to the local conditions (Dawson et al., 2016; Clay and Zimmerer, 2020; Fischer, 2021). At the global-level, these policies have led to the replacement of diverse traditional varieties with homogeneous certified varieties (van de Wouw et al., 2010), which, beyond posing threats to food security, raises concerns about the narrowing of the genetic base for adaptation to future conditions (Khoury et al., 2014; IPBES, 2019).

The agrobiodiversity-based narrative emerged as an alternative to reconcile agrobiodiversity, climate resilience, and smallholder farmers' knowledge and practices. This narrative is based on the crop diversity-stability hypothesis, according to wh ich, diversity at genetic and phenotypic level can contribute to stabilize production, buffer risks, and diversify diets and income sources (Cabell and Oelofse, 2012; Renard and Tilman, 2019). Agrobiodiversity-based narratives consider traditional crop diversity and farmers' knowledge as key sources of adaptation to climate change (Bellon and van Etten, 2013; Hellin et al., 2014; Altieri and Nicholls, 2017) and mostly rely on des-centralized, community-based approaches to agrobiodiversity conservation (Jarvis et al., 2011; Labeyrie et al., 2021a). Critics of this narrative emphasize that farmers maintain a diverse set of traditional crop species and landraces at the expense of more productive research-bred varieties that would improve their incomes and wellbeing (Mugwanya, 2019). Besides encountering limited institutional support, initiatives stemming from this narrative face multiple obstacles in their operationalization including insufficient consideration of local power dynamics (Nyantakyi-Frimpong, 2019; Porcuna-Ferrer et al., 2020) and a failure to adequately address smallholder farmers' local realities and situated needs (Jansen, 2015; Marfurt et al., 2023a). Case studies show that agrobiodiversity-based interventions require high labour- and time- investments (Dupré et al., 2017; Bezner Kerr et al., 2019; Laske and Michel, 2022), have limited economic viability (Galt, 2013; Dumont and Baret, 2017), and are often implemented 'for the sake of green agendas and white markets' (Marfurt et al., 2023b).

Empirical research shows the complexity of processes and multiple values guiding farmers' decision-making regarding what crops to grow (Demongeot et al., 2022). Thus, shedding light on this debate calls for nuanced and situated approaches that reflect on the myriad of drivers and trade-offs involved in farmers' decision-making and local shifts in crop diversity portfolios. In this work, we explore the situated causes and consequences of local agrobiodiversity dynamics in the light of climate change through a case study among the Bassari of south-eastern Senegal.

Our research tells the story of three traditional crops, namely fonio, sorghum and Bambara groundnut, which, despite their potential fit in the drier future climate of the region, are disappearing from the local agrobiodiversity landscape. We look at local agrobiodiversity dynamics from two complementary perspectives, bridging the critical reading of published

literature and secondary data with empirical research tapping on local ecological knowledge. Drawing upon political agroecology (Gonzalez de Molina, 2013), we aim to move beyond narrow narratives by unveiling the complexity of factors that shape agrobiodiversity dynamics. We highlight the importance of considering historical processes, structural inequalities, and power dynamics when examining crop diversity changes and smallholder farming communities' resilience to climate change.

Conceptual orientation: a political agroecology examination of local agrobiodiversity dynamics

To address why and how agrobiodiversity changes and what are the implications for climate resilience, we rely on a conceptual orientation that accounts for the multi-dimensional dynamics of agrobiodiversity. We build on political agroecology and related scholarship stressing the importance of considering how local processes of agrobiodiversity change interact with the wider economic and political environment (Bezner Kerr, 2013; Nyantakyi-Frimpong and Bezner-Kerr, 2015). Central to this conceptual orientation is understanding crop diversity dynamics as politically grounded and embedded in particular views, strategies, and interests between actors and power structures (Gonzalez de Molina, 2013).

Methodologically, political agroecology approaches call to consider cross-scale dynamics (Wittman et al., 2017; Zimmerer et al., 2019), power (Carney, 2002; Bezner Kerr, 2013; Flachs, 2019), and history (Fischer, 2021; Zimmerer et al., 2021) to analyse shifts in farmers crop portfolios. Following this research line, we take a diachronic, multi-scale, and situated approach to understand local agrobiodiversity dynamics within broader processes of agrarian change.

To understand contemporary rationales of Bassari farmers for crop choice, we place farmers' choices in their historical context, with reference to the particularities of south-eastern Senegal and the Bassari territory. We provide an overview of the historical stages of agricultural development and trace back the story of sorghum, fonio, and Bambara groundnut in parallel to that of socio-economic and political developments at regional, national, and local levels. We then examine current trends in the cultivation of Bassari traditional crops and local explanations for these trends as a point of departure to understand farmers' motivations for crop choices.

This conceptual orientation allows us to capture the complex and iterative nature of farmers' decisions on which crops to grow. We engage with a series of political ecology works (e.g., Bezner Kerr, 2014; Ribot, 2014) to elucidate how and why farmers change their crop portfolios, thereby showing how resiliencies and vulnerabilities to climate change are locally constructed.

Case study

The Bassari of south-eastern Senegal

Our research is based on a case study among the Bassari[2] of south-eastern Senegal (Figure 5.1). The Bassari inhabit in a region of the tropical savannah with dry-winter characteristics (Peel et al., 2007) characterized by a unimodal rainy season approximately spanning from June to October and a mean annual rainfall of 1096 mm (in 2019) (ANACIM, 2020). The Bassari live in a low density area, with 11 inhabitants/km^2 compared to the national mean of 82 inhabitants/km^2 (ANSD/SRSD, 2019). The area has limited access to public health and education. The Bassari territory was not well connected to the centers of French colonial administration nor to the Senegal centers after independence (i.e., Kédougou, Saint Louis, Dakar) (Nolan, 1986), although connectivity has improved over the last fifty years.

Bassari agricultural system is based on slash-and-burn shifting cultivation of cereals and legumes along with minor crops for the kitchen and market needs. Some families grow cotton and small-scale horticulture as cash-crops. Women and men carry their agricultural activities independently and control their own harvests. For the Bassari, some crops are gender specific –e.g., Bambara groundnut, peanut, rice, and fonio are grown mostly by women and sorghum and cotton are grown mostly by men. Maize is equally grown by men and women. Agriculture remains largely un-mechanised and only some families have access to oxen-driven ploughs. Communal labour arrangements based on mutual aid among kin and kith are widespread and embedded in the village traditional social organization. Even though there is no private land titling and access to land relies on customary use and access rights, Bassari increasingly seek to obtain formal land recognition to be able to bequeath and/or sell the land (Porcuna-Ferrer et al., 2024b).

The Bassari territory provides an interesting case to understand the complexity of relations between climate, agrobiodiversity, and farmers' decision-making for several reasons. First, rain-fed agriculture is Bassari main economic activity[3], making them vulnerable to climate change impacts –i.e., high variability of inter-annual precipitation, shortening and delaying the rainy season, and temperature increase (Sultan and Gaetani, 2016) (see Figure 1s in Appendix 3). Second, Bassari farmers have historically cultivated a wide diversity of traditional crops and landraces that are nowadays found in the same fields than exotic crops and research-improved varieties (Porcuna-Ferrer et al., 2023b). Third, there is a rare availability of baseline agricultural data for the Bassari. From 1949 until 1980s, ethnographers from the 'Musée de l'Homme' (Paris) regularly visited the area producing a rich body of literature that covers aspects related to cultural, environmental, and social life.

[2] The Bassari (*Ilian* in local language) traditionally inhabited the transboundary area between south-eastern Senegal and northern Guinea, and currently have a total population of approximately 20.000 inhabitants. We worked with the Bassari living in south-eastern Senegal.

[3] In the Kédougou region, 69% of households practice agriculture as main activity in 2013 (ANSD/SRSD, 2019); in the Bassari territory this percentage is probably higher.

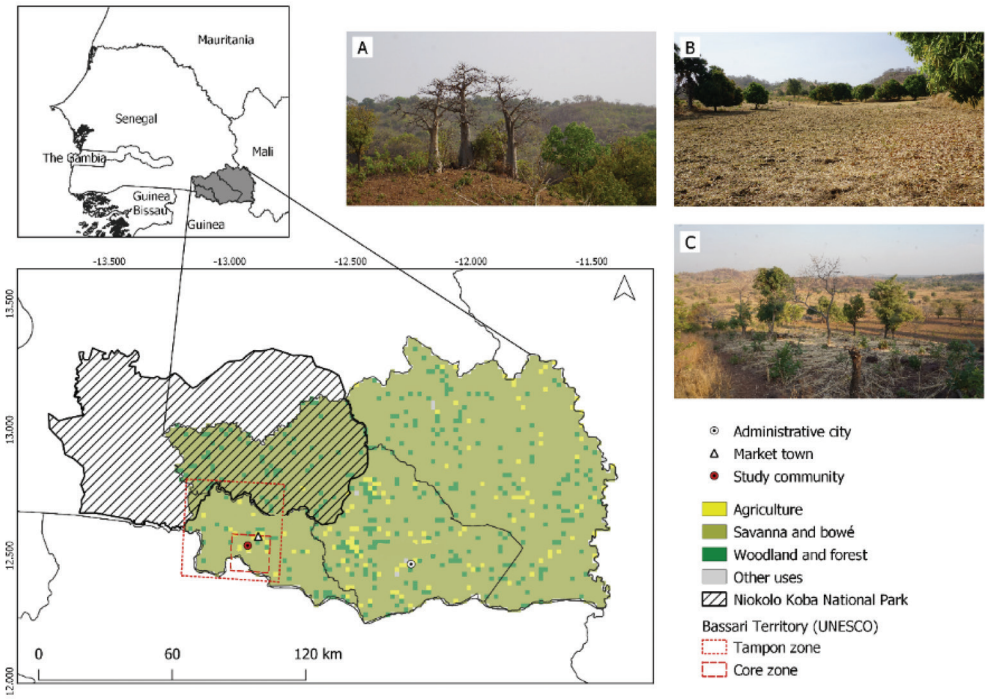

Figure 5.1: Study site land-use map and illustrations of the different field types. A) *Oxenga*, land on the hills; B) *eden*, land on the planes; c) *enam*, land surrounding the houses.

Bassari traditional crops

We focus on sorghum (*Sorghum bicolor* [L.] Moench), white fonio (*Digitaria exilis* [Kippist] Stapf), and Bambara groundnut (*Vigna subterránea* [L.] Verdc.), crops traditionally cultivated in our study area (Figure 5.2). These are crops endemic to Sub-Saharan Africa and their domestication history has conferred them with drought-tolerant biological traits –e.g., well-adapted to poor soils, heat, and high precipitation variability; see Hadebe et al. (2017) for sorghum; Abrouk et al. (2020) for fonio; Aliyu et al. (2016); and Mayes et al. (2019) for Bambara groundnut.

In Senegal, these crops are mostly linked to subsistence farming and their cultivation is nowadays marginal (FAOSTAT, 2021), particularly for fonio and Bambara groundnut, which are mostly cultivated in rural areas. The three crops have high nutritional values –see Anglani (1998) for sorghum; Koroch et al. (2013) for fonio; and Tan et al. (2020) for Bambara groundnut.

Sorghum, fonio, and Bambara groundnut have a marked cultural importance among the Bassari. For example, Bambara groundnut, the first crop cultivated by the Bassari according to their creation myth, cannot be sold, only given, and sorghum beer plays a central role in all Bassari customary practices (Gessain and Lestrange (de), 1987; Gessain, 1996). The mix of

Figure 5.2: Bassari traditional crops. (A) Bambara groundnut; (B) Sorghum, (C) Fonio.

sorghum and Bambara groundnut is used to cook *enap*, Bassari main staple dish (Gessain, 2010). Fonio used to be a 'back-up crop' eaten in the lean season, since its harvest came earlier than the other crops, although nowadays fonio is mostly used to cook meals for major festivities and celebrations.

Methods

Data collection

Our data collection built on two complementary data sources. First, we built on secondary data (literature and statistical data) to understand how externally driven changes in the local ecological, political, and economic systems affect the way in which local farmers and communities manage their agrobiodiversity. Second, to complement the historical sources and better understand contemporary drivers of change, we built on first-hand data on Bassari cultivation trends of traditional crops and explanations of the observed trends. To enrich the insights gathered through more systematic data collection we draw on ethnographic methods –first and forth authors lived in the case-study village over a period of 16 months–, which provided space for informal conversations and daily interactions with community members' agricultural activities and village life.

We acknowledge that our background and positionality might limit our capacity to assess local explanations of trends and drivers of change presented in this paper. Four out of the five authors of this work (including the first author) are from Europe, and the Senegalese author does not

belong to the Bassari ethnic group. Our disciplinary backgrounds (ecology, agronomy, anthropology, and economics) also affect our framing of a political agroecology based alternative narrative, which is largely influenced by Western epistemic traditions.

Before data collection, we obtained the permit to conduct research from the village authorities. We conducted meetings with all official and customary authorities, where research was presented and the conditions for conducting it were discussed. We also obtained Free Prior and Informed Consent from each person participating in the research. The Ethics Committee of the Universitat Autònoma de Barcelona approved the research (CEEAH 4903). Data collection took place with the help of local interpreters who translated from the local language (Bassari) to French.

Changes in the cultivation of Bassari traditional crops from an historical perspective

We reviewed secondary English and French literature for different historical periods in West African, Senegalese, and Bassari history. Given that the searched information most likely is not indexed, we did not conduct a systematic literature review. Instead, literature was selected in an iterative process, including author and keyword searching, and snowball referencing.

We compiled all the information available referring to the Bassari agroecosystem and agrobiodiversity dynamics (local scale), and agricultural developments, interventions, and crop diversity introductions between the 1900s until nowadays (national and regional scales). Our final review included peer-reviewed literature, ethnographies, historical texts, missionary and colonial agricultural officers' reports, and reports from the department of agriculture (Table 5.1). For the period of 1960s to nowadays, we also reviewed agricultural policies and reports of development aid in Senegal. We consulted both, published and non-published texts. Archival search was conducted at the National Archives of Senegal (Dakar), the Institut Fondamental de l'Afrique Noire (IFAN, Dakar), the Musée de l'Homme (Paris), the Bibliothèque Centrale du Muséum national d'histoire naturelle (Paris), and Stabi, Berlin (Staatsbibliothek zu Berlin). We also collected statistical data on crop area harvested between 1980-2022 for the Kédougou region (DAPSA, 2014; ANSD, 2023).

To fill the gaps between the historical information on trends and the real impact of these trends at the local scale, during October-December 2020 we also conducted key-informant interviews (n = 15, 20% women) with researchers with experience in the area, representatives from Senegal national and private agriculture institutions, farmers cooperatives, extension services officers, and representatives of non-governmental organizations (NGOs) working in our case-study region (Table 5.1).

Local explanations of trends and drivers in Bassari traditional crops

We collected primary data from November 2019 to March 2020 in one of the largest Bassari villages of Kédougou (Figure 5.1), with approx. 986 inhabitants (ARD, 2018). Data collection followed two phases.

On the first phase, we conducted a survey (n = 49, 41% women) to get detailed household information on crop diversity trends and drivers. Households were selected using stratified ran-

dom sampling, aiming at capturing the diversity of socio-economic status present in the local community. Fieldwork was interrupted by the Covid-19 pandemic, for which we could not conduct all surveys scheduled. Within each household, we interviewed either the man or the woman household head, aiming at having a balanced gender distribution. We used a timeline exercise to elicit household information about crop adoption, maintenance, abandonment and change in cultivation surface (i.e., increase, no change, or decrease) for each of the crops cultivated by a household since its establishment. We started by asking 'compared to when you started farming on your own, what changes have taken place in the diversity and abundance of the crops your household cultivates?' This open-ended question was followed-up by more direct questions (e.g., 'since you started cultivating on your own, have you / somebody from your household decreased or abandoned the cultivation of any crop?' If yes, 'which one?'). For each crop diversity change mentioned, we asked about the reasons for the change.

In the second phase, we used semi-structured interviews with a different set of informants (n = 47, 28 % women) to gain in-depth understanding of the drivers that make farmers switch crops. Participants were selected with quota sampling, balancing our sample across age, gender, and household socio-economic status. The lower involvement of women was primarily due to logistical constraints, i.e., we had to conduct semi-structured interviews between the main harvest time and the preparation period of men's initiation ritual. Women were less available for interviews compared to men, as women, besides being farmers, also bear the majority of household caregiving responsibilities. We asked respondents to describe the drivers for each trend mentioned during the household survey (i.e., 'why', 'how' and 'when' questions). For each driver mentioned, we continued asking 'and why do you think that happened?' to capture the synergies and cascading effects leading to changes in the cultivation of Bassari traditional crops.

Data analysis

Explanations of changes in the cultivation of Bassari traditional crops from an historical perspective

Historical literature was reviewed and coded in NVivo. We present the results following three historical periods defined based on the main socio-economic and political changes in Senegalese history: 1900-1960 (pre-independence, colonialism); 1960-2000 (independence with socialist government and structural adjustment programs); 2000-nowadays (liberal period). For each period, we coded information on reported crop diversity, crop diversity trends, interventions, and crops affected by the interventions. We organized the information in a timeline that guided the construction of the narrative.

Statistical data of the crop area harvested (1980-2022) and climate trends (1922-2015) in the Kédougou region were visualized in a trend-line with the help of R package 'ggplot2' (Figure 1s and 2s in Appendix 3).

Table 5.1: Research design.

Unit of evidence	Method	Sample
Regional, national, and local socio-economic and ecological context surrounding the cultivation of Bassari traditional crops		
	Literature review	Peer reviewed papers (n = 31)
		Ethnographic research documents (n = 99)
		Explorer diaries (n = 5)
		PhD and Master thesis (n = 19)
		Reports from NGOs and international organizations (n = 7)
		Reports from colonial officers (n = 12)
		Government reports and national policy plans (n = 38)
	Analysis of quantitative data	Climate trends at regional level, 1922-2015. Source: ANACIM, 2020 (Appendix 3, Figure 1s)
		Crop area harvested at regional level, 1980-2022. Source: ANSD, 2023; DAPSA 2014 (Appendix 3, Figure 2s)
	Key informant interviews	15 adults, 12 men and 3 women. Participants included:
		Researchers with experience in the area (KI #1; KI #2)
		Local administrative and customary authorities (village mayor and elders) (KI #13; KI #14; KI #15)
		Representatives of:
		Local NGO (KI #3)
		National regional agricultural office (KI #4; KI #5)
		International NGOs (KI #7, KI #8)
		Regional offices of the cotton company (KI #6)
		Regional producers union of rice (KI #12)
		Fonio processing unit (KI #9)
		Local women group and local women's association (KI #10; KI #11)
Trends and drivers in the cultivation of Bassari traditional crops as perceived by the farmers		
	Household surveys	49 adults, 29 men and 20 women within an age range of 19-74 years old
	Semi-structured interviews	47 adults, 34 men and 13 women within an age range of 23-70 years old

Local explanations of trends and drivers of change in Bassari traditional crops

Semi-structured interviews were translated (Bassari to French) and transcribed using f4-software. Open-ended questions in household surveys were not voice-recorded and we only analysed the paraphrasing of the answers.

To assess crop diversity trends, we first coded verbatim answers in NVivo. We created three different variables: 1) crop species name (e.g., 'maize'); 2) trend (e.g., 'increase cultivated surface', 'abandonment'); and 3) drivers, for which we differentiated among 'environmental' (e.g., shorter rainy season), 'socio-economic' (e.g., decrease in labour availability), 'cultural' (e.g., dietary changes), and 'crop traits' (e.g., organoleptic traits). Within each driver category, we also inductively developed sub-categories (e.g., 'dietary changes' –> 'rice-based diet') (see Table 5.2 for the main driver categories; and Table 1s in Appendix 3 for the main trends). We visualized the connections between the different drivers using a concept map.

We analysed household survey data using descriptive statistics (frequency of times each trend and driver was mentioned). We used R package 'ggplot2' to visualize such information in a histogram.

Looking back: a short history of the agrobiodiversity landscape across scales

In this section, we examine the main socio-economic, political, and ecological events that, from 1400s until nowadays, have shaped the agrobiodiversity landscape that we observe now across regional (West Africa), national (Senegal), and local scales (Bassari territory) (Figure 5.3).

The colonization of the agrobiodiversity landscape: transatlantic slavery and the introduction of exotic crops (1400s-1900)

West African farmers actively contributed to the domestication of more than 2000 plant species (National Research Council, 1996, 2006, 2008). Important domesticates include sorghum, white fonio, Bambara groundnut, cowpea, millet, African rice, and yam (Harlan et al., 1979). The first colonial and trade expeditions, dating from the 15th century, had a big influence on West African crop diversity through the introduction and diffusion of new crop species and varieties (Alpern, 1992, 2008). Peanut (Bernards, 2019), Asian rice (Linares, 2002), maize (McCann, 2005), and manioc (Carter et al., 1994) were introduced in West Africa in the sixteenth century by Portuguese traders.

Little is known about pre-colonial farming practices among the Bassari. Explorer's diaries and ethnographic work suggest that by the 19th century, the Bassari –who were historically hunter-gatherers– had definitively adopted farming (Rançon, 1894; Delacour, 1909; Neveux, 1909) and relied mostly on sorghum, Bambara groundnut, fonio, and native tuber crops like yams and coleus (Gessain, 1975). Rice and peanut were cultivated in small areas. Peanut most likely arrived through exchange with the Coniagui traders. Considering that the neighboring Casamance was the epicenter of African rice cultivation in Senegal (Carney, 2002), it is also likely that during the 19th century Bassari farmers cultivated both the African and the Asian rice species.

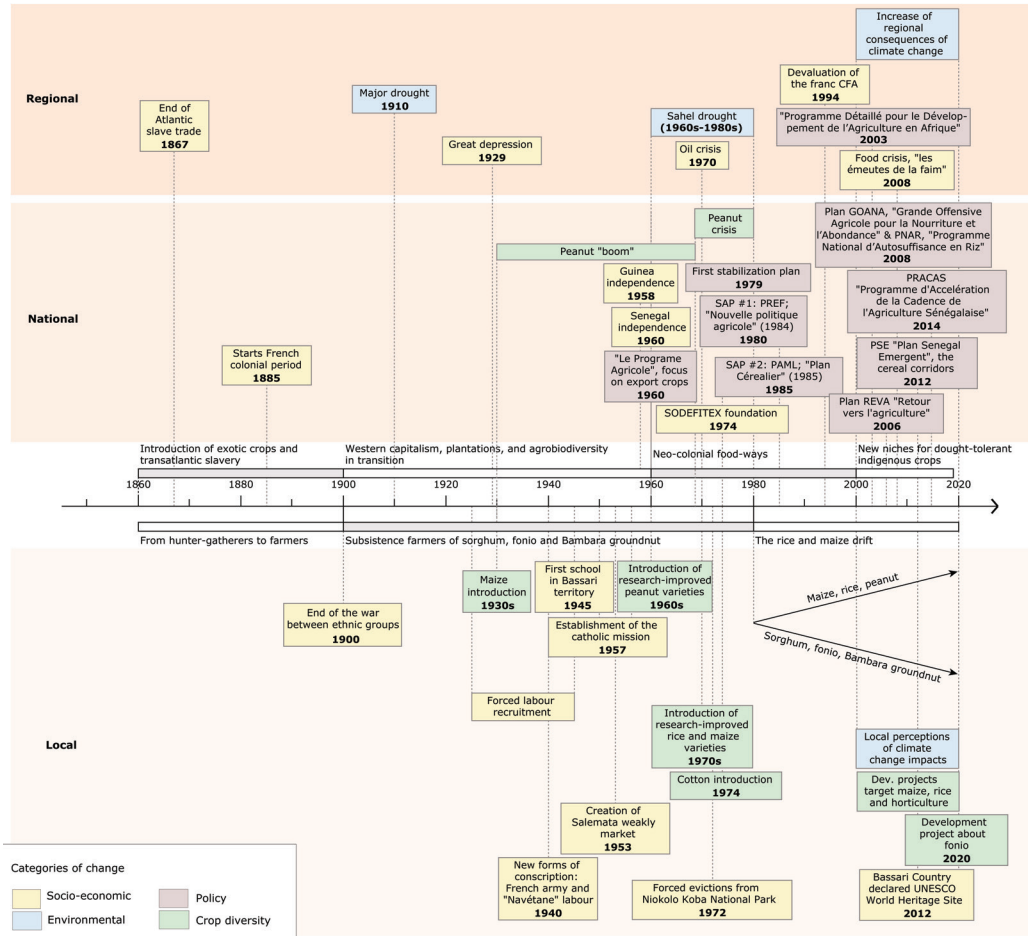

Figure 5.3: Timeline of socio-ecological events that influenced the diversity of Bassari traditional crops at the West African, Senegalese, and local scale.

Whose land? Whose crops? Capitalism and agrobiodiversity in transition (1900-1960)

Atlantic slave trade and early colonization destabilized traditional African societies, setting the base for Western Africa to become the plantation land for exotic species for export (e.g., cotton, peanuts, cocoa, coffee) (Carney, 2021). Most colonial agricultural scientists considered West African crops, varieties, and farming techniques inferior to European ones, which led to the imposition of Western agricultural practices (e.g., mono-cropping, pesticides) that did not align well with local socio-ecological farming conditions (Tilley, 2011; Hardin, 2021). In Senegal, the colonial period was characterized by the specialization in large-scale commercial peanut production for export and by the promotion of rice imports from French colonies in Indochina (Brüntrup et al., 2006; Bernards, 2019).

Driven by the growing demand for plant oils in industrializing France, peanut specialization started in the mid-19th century and had a boom after the 1929 Great Depression. Large-scale peanut production was possible due to the mobilization of forced labor through poll taxes and the construction of a transport network that allowed exports and shaped the geography of peanut production (Brooks, 1975; Bernards, 2019). As other ethnic groups, the colonial rule affected the Bassari through the establishment of new labor relations in the form of 'forced labor' in Wassadougou sisal plantation and in local roads' construction (1920s-1940s), and in the form of 'navetane labour'[4], which entailed going to the Groundnut Basin to work during the rainy season (Nolan, 1986). With the expansion of peanut cultivation, Bassari also engaged in peanut trading, mainly with middlemen who regularly visited their villages. The possibility of earning cash probably boosted local peanut production (Crepy-Montal de, 1984).

The French colonial regime also developed a network of weekly markets promoting local trade and cash circulation to pay the poll taxes (Gessain, 1975; Fouchier, 1981). The importance of money increased and commerce started to thrive in the Bassari territory (Gessain, 1967, 1975; Delacour, 1909). The new labor geographies and market-settings stimulated inter-ethnic contacts and knowledge and seed exchange, which brought new crops and varieties into the Bassari crop portfolio –e.g., maize was introduced around the 1930s and new rice varieties (e.g., 'malu siset'; 'malu bandyul') around the 1950s (Dupré, 1965; Gessain, 1975) .

Besides boosting the adoption of exotic crops, colonial years remarkably decreased Bassari access to wild biodiversity, an important pillar of their traditional livelihood, through the declaration of the Niokolo Koba National Park in an area that was traditionally used by the Bassari (and other ethnic groups) as hunting and gathering grounds (Gessain, 1975; DPN, 2000; Ece, 2008). Consequently, the importance of wild plant gathering and hunting in the Bassari diet shrink and the surface of agricultural fields gradually increased (Gessain et al., 1984; Gessain, 2010).

Colonial years also impacted the Bassari territory by promoting the contact with (and absorption of) Western culture, favored by two main interventions. First, the imposition of a Western schooling system (the first colonial school in the Bassari territory was constructed in 1947), which resulted in children spending less time in the *ambofor*, the school analogous in the Bassari traditional education system, and having less time for agricultural tasks (key informant 15, KI #15, Table 5.1). And second, the advancement of Christianity through the establishment of the Catholic and Protestant missions (in 1957 and 1960 respectively) (Guignard and Gessain, 1971; Gessain, 1975), which became a new source of agricultural knowledge, promoting new crops and management techniques.

In sum, colonial rule profoundly impacted the Bassari society and agricultural system through changes in labor regimes and relations, income sources, market settings, access to forests and bushlands, and cultural arrangements. New crops, varieties, and technical innovations permeated the

[4] *Navetane labour i*s a Wolof term that was used by the colonial administration to designate seasonal agricultural workers (Berg, 1965).

local agricultural system during this period. Although many of these innovations neither had been adopted by a vast majority of the local community, nor replaced traditional practices, the seeds of these changes were already planted.

Neo-colonial food-ways: Changing landscapes, changing vulnerabilities (1960-2000)

Post-colonial governments and international donors and projects, NGOs, and transnational companies promoted mono-cropping for export, dependency on external inputs, and diets based on food imports (mainly rice) and privileged peanut first, and rice, maize, cotton and horticulture later. Agronomic research agendas continued biased towards exotic crops and farmers' varieties were considered of lower value compared to the ones bred in research centers.

In 1960, with Senegal independence, started a period of state-led development that reproduced the structures and the specialization policy of the French colonial state. Senegalese government put into place the 'Programme Agricole' (1960-1980), which promoted peanut production and intervened in the rural areas providing farmers subsidized seed, chemical fertilizer, and marketing channels, and purchased most peanut production (Dieng and Gueye, 2005; Sall, 2015). New upright peanut varieties, easier to harvest and with higher yields, were distributed and rapidly replaced other varieties (Bonneuil and Thomas, 2009). Short-cycle peanut varieties arrived to the Bassari territory in the early 60s (Dupre, 1965) and were given to families within the framework of food aid or distributed at subsidized prices (KI #14).

Initial post-colonial years coincide with critical climatic and economic conditions, which entailed a 'double shock' in the national agricultural sector. The first shock was caused by severe droughts, which started in the 1960s and extended to the 1970s and 80s, and which largely impacted (predominantly rain-fed) Senegalese agriculture. This accelerated soil degradation and caused important production losses and famine. The shock reflected the limitations of the rural development paradigm that had driven agricultural policy during colonial and early post-colonial years –i.e., through the promotion of mono-cropping for export, chemical inputs, and land reforms that made large-scale agricultural intensification possible, not giving support to smallholder farmers and staple food production (Mackintosh, 1989; Dawson et al., 2016). The Sahel drought also hit the Bassari territory, although impacts were milder than in other areas. The mosaic of agriculture and forest patches created by slash-and-burn subsistence agriculture, the diverse crop portfolio, and a complementary livelihood base of wild edible plant gathering and hunting probably constituted key assets for Bassari resilience in the face of the 1970s droughts (Gessain, 1975; KI #15).

In Senegal, as in other West African countries, the drought and famine period resulted in additional efforts to increase the agricultural production and triggered scientific agricultural research through the creation of national agricultural research institutions[5] (Raimond et al., 2020). Between the 1972 and 1990, the formal seed system was consolidated and the production and diffusion

[5] The National Institute for Agricultural Research (ISRA, 'Institute Sénégalaise de Recherches Agricoles') was created in 1974.

of research-improved seeds expanded. The crop focus slowly widened, including exotic crops other than peanut, e.g., cotton for export and rice and maize for subsistence. During the years that followed, new short-cycle varieties arrived to the Bassari territory. In 1973-1979, Bassari farmers accessed research-improved rice and maize seeds, herbicides, and fertilizers[6]. In the 1980s, American cotton (*Gossypium hirsutum*)[7] covered the first hills of Bassari scattered agrobiodiversity landscape. Cotton seeds and inputs were provided to Bassari farmers through a debt system, according to which farmers would pay their debts by selling the cotton after the harvest (KI #15).

The severe drought period was followed by an economic shock. The collapse of the peanut sector, together with the 1970s oil crisis and economic recession in the Global North, precipitated the 'debt crisis' in the Global South, which materialized through the implementation of structural adjustment programs. Senegalese policies shifted from state-intervention to price-driven policies, leading to the liberalization of the food sector and to the disengagement of the Senegalese state from agricultural policy. In 1984, the 'New Agricultural Policy' was issued, with a focus on food self-sufficiency (i.e., 'Plan Cérealier', 1986 with a strong focus on rice) but lacking the needed economic investments for proper implementation (Oya and Ba, 2013). The state facilitated investments in cash crops for export by foreign (mostly Western) agribusiness firms (Mackintosh, 1989; Ndiaye, 2013; Sall, 2015). State gaps were filled by NGOs and international cooperation agencies (Boillat et al., 2022). During the 20th century, the reliance of national food security on rice imports steadily increased (Randolph, 1997; Diagne et al., 2012). This trend, which had started during colonial times, led to the gradual shift of national consumer patterns from local grains (e.g., millet and sorghum) to a rice-based diet (Colen et al., 2013).

During 1960-2000s, agriculture in the Bassari territory remained diversified and subsistence-based, although the shift to exotic crops continued. Peanut gained importance in women's fields in detriment of Bambara groundnut, and cotton was rapidly integrated into the traditional crop rotation. Maize started covering the area surrounding the houses. The riverbanks and adjacent areas, previously covered with gallery forests, started to be cleared up for rice cultivation (Gessain 1975; KI #14; KI #15). Traditional crops remained the basis of the diet, but –by the end of the 20th century– rice had already started to find its way into local kitchens, favored by seasonal migration, which gained momentum as a cash-earning strategy (Nolan, 1986). Together with the new crops and short-cycle varieties, the first chemical agricultural inputs and technical innovations, such as the oxen-driven plough, arrived during this period, although their use remained reserved to few (KI #6, KI #15).

[6] BAMTAARE –the rural development branch of the SODEFITEX, the cotton company– was responsible for farmers' training and for the distribution of rice and maize seeds among Kedougou farmers' (KI #6).

[7] American cotton had been introduced in West Africa as a cash-crop due to its higher yield, better fiber quality, and adaptation to mechanization compared to the perennial African-Asian varieties (i.e., *G. herbaceum*, *G. arboreum*) (Seignobos, 2019).

Maize and rice drift, and new niches for Bassari traditional crops (2000s-nowadays)

The start of the 21st century represented for Senegal an inflexion point in terms of agricultural policy, consolidating a shift from traditional to exotic crops. Crop diversity trends at regional level (1980-2022)[8] show a decrease in sorghum cultivation, an increase in rice, maize, and peanut cultivation, and an increase followed by a decrease in cotton cultivation (Figure 2s in Appendix 3).

Agricultural policy during this period was characterized by three main trends. First, facing the failure of the structural adjustment programs, West African states (including Senegal) re-engaged in agricultural development. The 2008 food crisis revealed the fragility of Senegalese (and global) food system, highly dependent on rice imports, and triggered the return of agriculture to the heart of public policies. In continuation with previous policies, new ambitious programs were implemented in Senegal to reinforce cereal production and national food security while increasing national production for exports. Examples include the special programs of maize, manioc, sesame, roselle, fonio, and sunflower, the plan REVA ('Retour vers l'Agriculture') in 2006, the plan GOANA ('Grande Offensive Agricole pour la Nourriture et l'Abondance') and the PNAR ('Programme National d'Autosuffisance en Riz') in 2008, and the PRACAS ('Programme d'Accélération de la Cadence de l'Agriculture Sénégalaise') in 2014-2017 (Figure 5.3). Although some Bassari traditional crops were targeted in these national programs, the main focus remained on exotic crops –like rice, maize, and horticulture– which received the biggest share of economic endowment (Ndiaye, 2013).

Second, as happened across Sub-Saharan Africa, there was a resurgence of agricultural intensification programs within the so-called 'New Green Revolution for Africa' (World Bank, 2007). The programs implemented during this period relied on market-led agricultural transformation for economic growth, subsidizing chemical inputs, mechanization, and facilitating land and water access for large-scale investors, which gave rise to land-grabbing (Koopman, 2012).

Third, the dependence of policy action on foreign funding, also called 'projectorate'[9], increased leading towards an agricultural development agenda ruled by the interests of foreign donors and reflecting the heterogeneous and often contradictory visions of different agricultural development actors (Bottazzi and Boillat, 2021). In this context, agroecological initiatives gained momentum, promoted by peasant organizations, NGOs, research centers and international donors. National and international agricultural research started to direct attention towards West African indigenous crops. Fonio and sorghum were in the spotlight of international plant breeding improvements (Diop et al., 2018; Xin et al., 2021; Kaczmarek et al., 2023). Still, due to the lack of financial and political autonomy of farmers' organizations, and the big economic and political stakes in driving the New African Green Revolu-

[8] Fonio only started being monitored in 2015, which is insufficient time to identify a clear trend. Bambara groundnut does not appear in the national agricultural statistics.

[9] 'Projectorate', is a term coined by Carmona (2008) to describe the logic in many countries of the Global South, where policy formulation and implementation is strongly influenced by transnational funding agencies. In the case of Senegal, it refers to the technical and economic support of foreign donors and international partners to implement agricultural development projects (Bottazzi and Boillat, 2021).

tion, most of the projects and initiatives (even those self-proclaimed as 'agroecological') followed the logics of agro-industrial development and food imports, promoting technology-driven approaches (Bottazzi and Boillat, 2021) and largely focusing on few mostly exotic crops and research varieties.

During this period, agricultural development in the Bassari territory reproduced regional and national-scale trends. State intervention took place through agricultural development projects that distributed subsidized research-improved seeds and chemical fertilizers and increased the dependence on chemical inputs. These projects mostly targeted rice and maize, which continued to gain popularity in farmers' fields and plates. Cotton continued to be promoted through contract-farming arrangements. Different international development organizations and NGOs intervened in the area providing materials, infrastructure, and capacity-building for small-scale horticultural production[10], which mostly targeted water-demanding vegetables for commercialization, increasing water demands for irrigation, groundwater depletion, and conflicts over water use. For the first time, local NGOs started including fonio in their crop repertoire, creating new niches for its production and use.

More broadly, the 2000s stabilized the trends that started in colonial and early post-colonial times, fundamentally changing local communities' access to natural resources, labor relations, income, and consumption patterns. Long-term and seasonal migration entrenched in Bassari livelihood strategies. The classification of the Bassari Country as a UNESCO World Heritage Site (UNESCO, 2012), the establishment of a tourist camp in the Bassari territory, and the improvements of the road connecting it with the administrative town (Kédougou) fueled the small-scale tourism sector. With the development of the gold mining industry in eastern Senegal (D'Avignon, 2018), working in the mining areas became common among youth. Common agricultural labour, deeply embedded in Bassari traditional social organization and rituals[11], loss importance (Yamada, 2007).

A contemporary look at Bassari traditional crops

To complement the view of global-, regional-, and national- scale dynamics, in the next section we present results from empirical research describing Bassari contemporary adjustments in crop portfolios, which we take as a point of departure to understand farmers' agency on how and why they make crop choices.

Current trends in the cultivation of traditional crops

In household surveys and semi-structured interviews, informants mentioned that the cultivation of sorghum, fonio, and Bambara groundnut has decreased in the Bassari territory.

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[10] Small-scale horticultural production is practiced mostly by women in the Bassari territory. It relies on manual irrigation with well water, it is done during the dry-season, and is mostly for local commercialization (own observation).

[11] Ethnographic texts highlight Bassari hierarchic and highly structured age-class system, which is considered the pre-requisite for acceptance and status in the village and the basis of most village activities, customary practices, and agricultural tasks. From the time young men and women are initiated, until they enter the class of the 'elders', Bassari are expected to conduct a certain number of ritual tasks per year, most of which relate with agricultural activities and communal labour arrangements (Nolan, 1975; Gessain, 2002; Yamada, 2007).

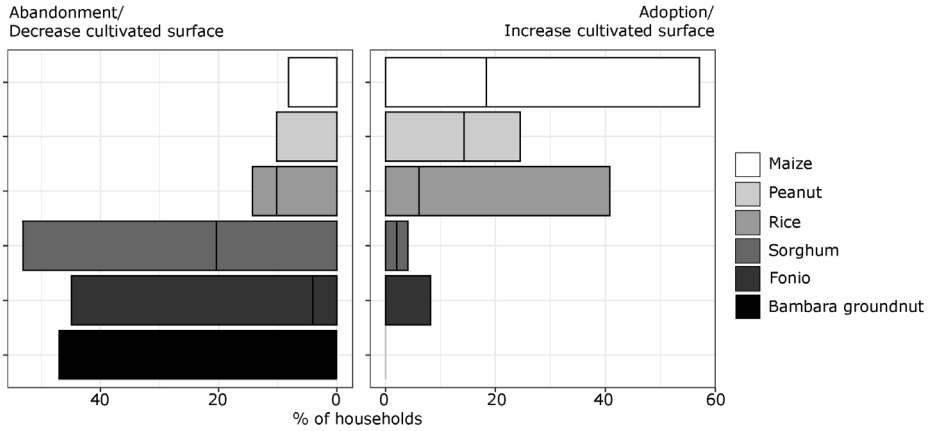

Figure 5.4: Percentage of households that adopted or increased the cultivated surface (right) or that abandoned or decreased the cultivated surface (left) for each local staple crop. The percentage is calculated over the total number of households surveyed (n = 49).

According to household survey results (Table 1s in Appendix 3), in the 2019 cropping season, less households cultivated Bassari traditional crops than rice, maize and peanut. Concretely, 59.2% (n = 29) of the households cultivated sorghum, 36.7% (n = 18) cultivated fonio (n = 23), and 51% (n =25) cultivated Bambara groundnut, compared to the 100% (n = 49), 87.8% (n = 43), and 100% (n = 49) that cultivated maize, rice, and peanut.

Households are also reducing the surface cultivated with Bassari traditional crops. While 20.4% (n = 10), 4.1% (n = 2), and 34.7% (n = 17) of the households mentioned having reduced the surface cultivated with sorghum, fonio, and Bambara groundnut since the establishment of the household, only 8.2% (n = 4), 10.2% (n = 5), and 10.2% (n = 5) mentioned having reduced the surface cultivated with maize, rice, and peanut. In contrast, since their establishment, households were more likely to increase the surface cultivated with maize (18.4%, n = 9), rice (6.1%, n = 3), and peanut (14.3%, n = 7), than to increase the surface cultivated with sorghum (2%, n = 1), fonio (0%, n = 0), and Bambara groundnut (0%, n = 0) (Figure 5.4).

As the most prominent trend is the decrease of surface / abandonment in the cultivation of Bassari traditional crops, we focus on this change in subsequent sections.

Local explanations of the abandonment of Bassari traditional crops

In the household surveys, respondents gave 124 responses to the question of why they have abandoned sorghum, fonio, and Bambara groundnut. Responses include 'socio-economic' (38.7%, n = 48 responses), 'cultural' (13.7%, n = 17), and 'environmental' (8.9%, n = 11) drivers, as well as 'crop traits' (36.3%, n = 45), which are indirectly related with the three other categories (Table 5.2). We complement these explanations with in-depth information collected through semi-structured interviews.

Table 5.2: Drivers of abandonment or decrease in the cultivation of Bassari traditional crops. Data obtained through household surveys (n = 49). Columns contain the number of times each driver was mentioned per crop (in total and in percentage).

	All crops together		Sorghum		Fonio		Bambara groundnut	
	Total	**%**	**Total**	**%**	**Total**	**%**	**Total**	**%**
Environmental								
Shorter rainy season / rainy season starts later / rainy season finishes earlier / decrease mean rainfall	8	6.45	6	13.33	2	4.55	0	0.00
Increase in the frequency of crop pests and diseases (production, storage)	3	2.42	1	2.22	0	0.00	2	6.25
Socio-economic								
Trade-offs with other crops	7	5.65	5	11.11	2	4.55	0	0.00
Decrease seed access and availability	4	3.23	1	2.22	0	0.00	3	9.38
Decrease labour availability / lack of manpower	29	23.39	7	15.56	13	29.55	9	28.13
Decrease land access / availability	2	1.61	1	2.22	1	2.27	0	0.00
Crop damage / failure / loss	6	4.84	3	6.67	1	2.27	2	6.25
Cultural								
Changes in food habits / dietary changes	9	7.26	6	13.33	0	0.00	3	9.38
Decrease communal agricultural labour	6	4.84	1	2.22	4	9.09	1	3.13
Loss of traditions / decrease use of ritual foods	2	1.61	2	4.44	0	0.00	0	0.00
Crop traits								
Organoleptic traits (colour, taste, smell, consistency)	2	1.61	1	2.22	0	0.00	1	3.13
Use-related traits (processability, marketability)	4	3.23	0	0.00	3	6.82	1	3.13
Management-related traits (workload)	30	24.19	7	15.56	13	29.55	10	31.25
Agronomic traits (crop cycle, yield, height)	9	7.26	3	6.67	4	9.09	2	6.25
Others								
Other reasons	1	0.81	0	0.00	1	2.27	0	0.00
No answer	2	1.61	2	4.44	0	0.00	0	0.00

Socio-economic changes, and specifically lack of access to labour, land, or seeds were the most mentioned drivers that explain the abandonment of Bassari traditional crops. Particularly, the decrease in labor availability was the main reason used to explain the abandonment of Bassari traditional crops (23.4 %, n = 29).

As a middle-aged man explained, '*You need a big family to cultivate sorghum*' and he continued '*the work is hard. You start the first and finish the last*'. Another aspect mentioned to contribute to the higher workload of sorghum compared to maize was the need for bird-scaring labour close to harvest. As an old-man indicated: '*I used to cultivate a big field* [of sorghum] *but, as neighbours abandoned sorghum cultivation and children started going to school, all birds feasted on my field. I was discouraged. I was cultivating for the birds!*' Decrease in labour availability was also tightly linked to the decrease of communal agricultural labour (4.8 %, n = 6) (e.g., decrease in neighbourhood or village common working days in one person's field). As a middle-aged woman explained: '*We fail to grow it* [fonio] *because we don't have anybody that helps us in our fields. Before the children from all the neighbourhoods would organize themselves to harvest all the fonio fields of the village. (…) All non-initiated boys had to do it without expecting anything in return. (…) It was their duty. (…) Nowadays everyone is for himself and God for all of us*'. Another commonly mentioned cause of the decrease in labour availability was age. This reason was related with generational change and the lack of relay from the youth within the household for the cultivation of traditional crops. As several young respondents mentioned, Bassari traditional crops do not always fulfil their expectations: '*My mother and my grandmother cultivated it. But the harvest is hard, you need to spend all day bended down in the field to harvest only a small bit. People prefer peanut. It is faster. It gives more and it is easier to harvest. I didn't even ask for the* [Bambara groundnut] *seeds to my mother*'.

Respondents also explained the abandonment of traditional crops as a consequence of the high work demands of these crops, either during harvest 'management-related traits' (24.6 %; n = 30) or processing 'use-related traits' (3.2 %, n = 4). Lower labour requirements were mentioned for maize versus sorghum and for peanut versus Bambara groundnut. The high work demands of Bassari traditional crops were especially important for women. Both, Bambara groundnut and fonio are fundamentally women's crops, which entails that women assume most tasks related to their cultivation and post-harvest. Women are also the ones in charge of household meal preparation and therefore, the ones assuming the burdensome processing tasks of traditional crops. As one young woman stated: '*Preparing fonio is difficult and very time-intensive. It's hard to cook and crush it in the mortar*'.

Respondents also mentioned 'trade-offs with other crops' (5.6 %, n = 7) as reasons leading to the abandonment of traditional crops. Rice, maize, peanut, and cotton were generally perceived to have higher yields, better response to fertilizer, and easier mechanization than Bassari traditional crops, and thus farmers prioritized them. '*People used to cultivate them* [traditional crops] *because there was no alternative. Nowadays new seeds arrived* [refers to maize and rice]. *With the help of the herbicides and the oxen-plough, everybody wants to cultivate in the plains. (…) Cotton is another thing. (…) For many of us, cotton is the only option to earn the money to pay children's schooling. You can have 100 cows, or 50 sacks of grain, but whom are you going to sell them to?*'

However, cotton is socially considered a men's crop and the decision to grow cotton seem to be mostly a men's decision, probably because men are the ones who have contact with the extension services of the cotton company and access to credit. Women complained that cotton cultivation brought household food insecurity due to land and labour trade-offs with subsistence crops. Several women also complained that their husband's 'drank' cotton revenues. Men's excessive spending on alcohol was a source of conflict between spouses and affected households' economy, which did not always benefit with cotton sales income. While some men mentioned they could buy status items (e.g., mobile phone, motorbike, etc.) with cotton's revenues, none of the women interviewed mentioned it.

Another socio-economic reason for the decrease in cultivation of Bassari traditional crops were shocks in the farming system causing 'crop damage, failure, or loss' (4.8%, n = 6). For example, several respondents mentioned being discouraged from cultivating Bambara groundnut due to free-ranging cows: '*People leave their cows free at the end of the harvesting season, so that they eat the crop residues. (...) Bambara groundnut is slower than peanut, that's why it's still on the fields when the cows come. If you don't take good care, cows will eat all your harvest*'. Similarly, some respondents also noted abandoning fonio due to harvest damage caused by livestock grazing and trampling: '*We have cultivated fonio since we were young. It is an easy crop. It grows everywhere and you don't need to check it closely. After sowing, you can return home without worrying about the birds or the rodents because when you return to your field, you will see that it has germinated. But nowadays, if you don't surveil your field closely, the cows will eat all the grain. Nowadays, it's the free roaming cows that discourages us* [from growing fonio]'. Besides free ranging livestock, farmers also mentioned fonio losses due to early grain shattering, which posed problems if they could not harvest on the (short) optimal time window, and low seed quality, i.e., fonio seed mixed with grasses.

After socio-economic factors, the second most important group of drivers contributing to the abandonment of Bassari traditional crops were cultural changes. Within cultural changes, dietary changes, i.e., shift of people's preferences from a diet based on traditional crops to a rice- and maize-based diet, were the most prominent. 7.3% (n = 9) of the reasons mentioned for crop abandonment referred to 'changes in food habits' and 1.6% (n = 2) to 'organoleptic traits' (e.g., colour, taste, smell, consistency). As a middle-aged woman noted: '*Children don't want to eat* "*enap*" *anymore*'. Several respondents emphasized that they preferred maize and rice to sorghum and Bambara groundnut for their taste. Some respondents also mentioned that eating *enap* is old-fashion. In contrast, fonio is still a highly valued crop in terms of taste, as a woman respondent said: '*I always cultivate a bit* [of fonio] *because it's very tasty and filling, but light in the stomach*'.

Environmental changes were the least frequently mentioned to explain the decrease in the cultivation of Bassari traditional crops. Within this category, the main drivers were the 'shorter rainy season' (6.4%; n = 8) and the preference towards short-cycle varieties –'agronomic traits' (7.3%; n = 9)–, both tightly linked. When discussing preferences towards short-cycle varieties, Bassari farmers referred to changes in rainfall abundance and distribution, which includes an increase of the length and frequency of dry-spells, a higher unpredictability, variability and intensity of the rains, and a later onset and earlier end of the rainy season. To react to these changes in rainfall

patterns, farmers have started to rely more on short cycle varieties, which can produce during the central months of the rainy season, with lower risks of crop losses. '*Now the rainy season stops very early and the Bambara groundnut is very slow. You need to sow it before peanut and harvest it last*', complained an older woman while we crossed freshly harvested fields. Few meters further, a drab-brown field full of yellowish grasses. '*This is my fonio field*' she stated, and she continued '*It had no time to ripe because the rain stopped too early*'.

Finally, Bassari acknowledge that socio-economic, cultural, and environmental drivers result from a range of other underlying factors that mostly relate to lifestyle changes (e.g., people now invest less time in agriculture and other subsistence activities), changes in the traditional value-system (e.g., age-class system and the traditional agricultural labor arrangements decrease in importance), and the effects of these factors on farmers' crop diversity preferences and the way they do farming. Figure 5.5 offers a visualization of the complex interactions between drivers that are locally perceived to have caused a decrease in Bassari traditional crops.

An example of this complex interactions is the 'decrease in labour availability', which Bassari acknowledged as simultaneously caused by youth migration, mandatory schooling, and the decreasing importance of traditional customary practices, particularly the age-class system that used to structure communal labour arrangements. For example, as mentioned, fonio harvest was traditionally done by the youth as part of the corpus of ritual duties that conforms Bassari age-class system, but now needs to be assumed by each individual farmer, making it especially difficult for smaller or less wealthy households to mobilize enough workforce.

Other examples of such complex interactions refer to 'increase in crop damage, failure or loss'. According to the Bassari, mandatory schooling resulted in children spending less time in the fields, and therefore doing less bird scaring labour, which, together with the reduction of size and number of fields of Bassari traditional crops (mostly sorghum), led to an increase of crop losses due to birds. Bassari also acknowledged the complex cascading effects of cow introduction in crop losses. The prohibition of hunting and the increase in livestock market value led to increasing livestock rearing, which in turn led to an increasing conflict between crop cultivation (specially Bassari traditional crops due to their longer cycles and higher labour requirements) and livestock free ranging.

Respondents also related the decrease in the cultivation of traditional crops with general lifestyle changes and with changes in the role that these crops play in the Bassari society. Bassari traditional crops used to be essential for the traditional diet and for many ritual practices that have now been abandoned. For example, having a big sorghum field was part of Bassari men initiation ceremony. Nowadays, this does not seem to play an important role anymore. Respondents also explained that the number of rituals in which sorghum beer is consumed has decreased. As one middle-aged man explained '*As a part of the initiation, you had to bring seven vessels full of sorghum to the sacred forest and then all the initiated men would share the beer. (…) Afterwards people started thinking that giving away so much grain for offering free beer was too much waste. (…) They* [the elders] *realized that times were changing and there was no other alternative than accepting*'.

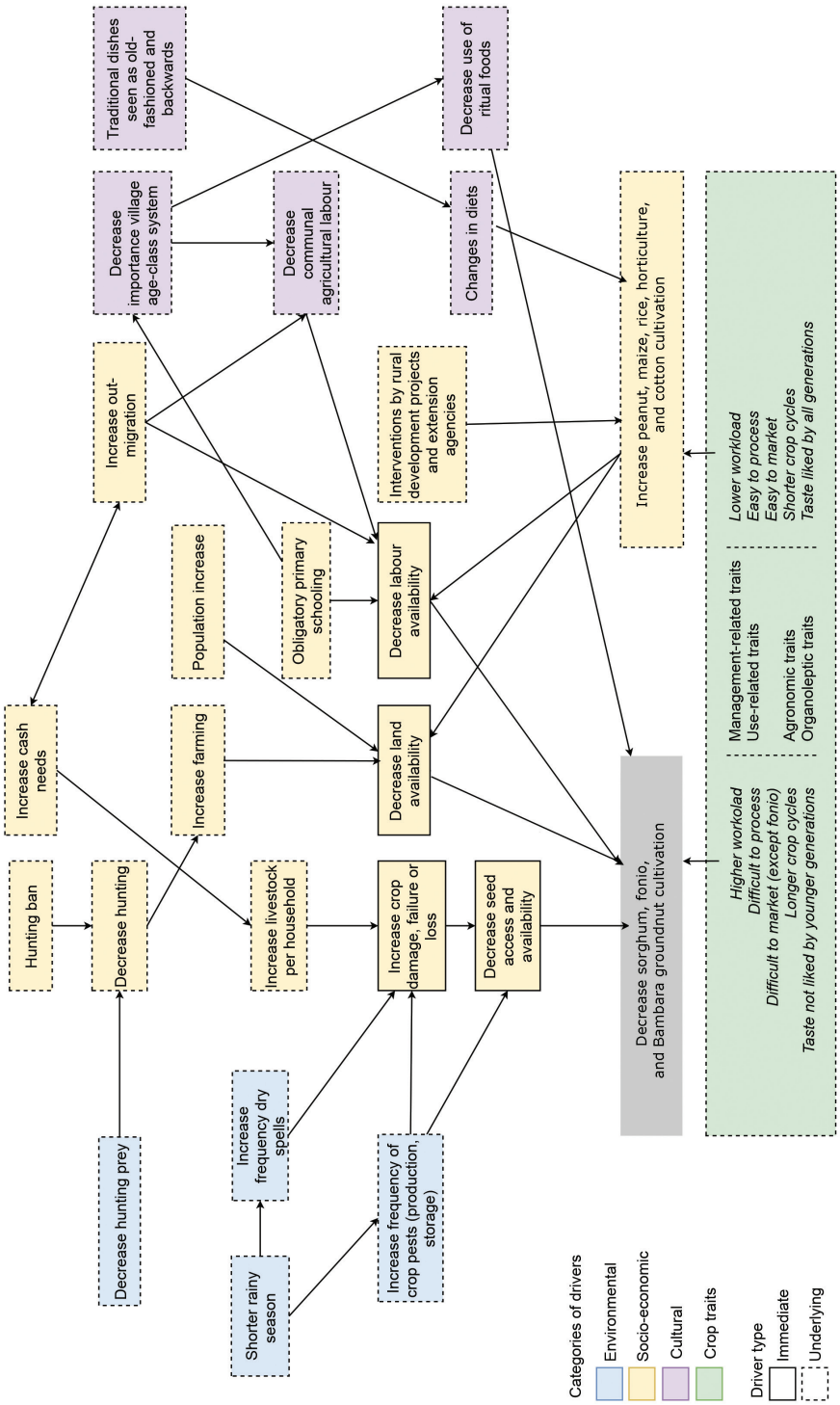

Figure 5.5: Example of the locally perceived cascade of change associated to the cultivation decline of Bassari traditional crops. For the synergies between the drivers of crop trends, we differentiated between 'immediate' and 'underlying' drivers depending on whether the mentioned driver referred, respectively, to the final cause that led to crop abandonment or to non-final causes that put other drivers in motion.

Discussion and conclusions

In this study we place three Bassari traditional crops at the heart of our analysis to explore the multiple drivers involved in their decline in south-eastern Senegal, a region especially vulnerable to climate change. Our results show that farmers' crop choices are multi-causal and point to the importance of understanding how power-laden broader political and economic forces interact with household dynamics materialized through everyday decision-making and labour distribution. We discuss how the shift to exotic crops transformed farmers' fields and intra-household power relations with consequences for farm self-sufficiency, family nutrition, gendered power relations, and resilience and vulnerability to climate shocks.

Before reviewing our results, we discus three caveats of our research. First, due to the lack of Bassari written records, all the secondary data analyzed was written by outside observers. These texts mostly reflect mainstream development narratives and likely provide limited understanding of local people's lives, perspectives, and processes of change. Reliance on these texts might bias our understanding of change. Second, we aimed at creating new understandings of agrobiodiversity dynamics by integrating multiple evidences (Tengö et al., 2014). However, the unequal power relations between academic knowledge and Indigenous and local knowledge embedded in imperialism, colonialism, and capitalism make bridging epistemological boundaries a 'contested process', with an inevitable reproduction of structural inequalities (Chilisa, 2017). Acknowledging this problem, we ask to consider the Bassari views presented here as our own interpretation, and not Bassari worldviews and knowledge. Third, the case-study nature of our research limits our ability to generalize results. We do not claim that our results are representative of global dynamics of sorghum, fonio, and Bambara groundnut, but only to the Bassari territory, where our qualitative results are in line with the crop diversity trends observed at broader scales (e.g., Diop et al., 2018; Sidibé et al., 2020). We do argue, however, that our results capture the complexity of local agrobiodiversity trends, and the interactions and interdependencies of these trends with historical and political changes taking place at larger scales, which eventually affect communities' and agroecosystem's resilience to climate change in the Bassari territory and elsewhere. We discuss our results from this perspective.

Current farmers' crop diversity choices reflect multi-scalar and diachronic complexity

Our findings highlight how Bassari farmers see their choices increasingly dictated by external forces. Since the 1900s, West African regional agricultural policies and interventions have promoted exotic commodity crops through different strategies, ranging from coercion and poll-taxes during the colonial period to seed and inputs provisioning, agricultural extension, marketing boards, and NGO intervention, more recently. Besides introducing new crops and varieties, colonial processes changed the structural and material context in which farmers' decisions took place –e.g., cash needs and migration increased, the time and labour available for farming decreased, and dietary preferences changed. In parallel, researchers privileged work on exotic crops with higher competitive advantages in terms of yield and management-related traits compared to the available varieties of Bassari traditional crops

(Tadele and Assefa, 2012; Chivenge et al., 2015; Manners and van Etten, 2018). Combined, these drivers affected Bassari farmers decisions to switch from traditional to exotic crops, which materialized in the explanations farmers provided for the abandonment of sorghum, fonio, and Bambara groundnut –e.g., changes related to cultural norms and traditions, dietary preferences, and land/labour trade-offs with other crops.

Our findings speak to research in other parts of the world that explore the situated effects of policies and market integration on local agrobiodiversity and farmers' decision-making. This literature shows how colonization, globalization, and in general policies and initiatives that orient agriculture towards global markets lead to a loss of traditional crops and varieties (Maikhuri et al., 1997; Teeken et al., 2012; McLean-Rodríguez et al., 2019). Additionally, our results highlight labour relations as a key element that materialized the local effects of broader socio-economic forces. Bassari traditional crops depended on labor-intensive forms of agriculture. Broader socio-demographic changes, such as children schooling and youth migration, acted synergically with the decrease in importance of rituals and cultural norms, steering agricultural common working days, and affecting household labour availability. Nonetheless, our results further advance that broader drivers are crucial, but not enough, to explain changes in labour relations and the decrease in cultivation of sorghum, fonio, and Bambara groundnut. Hence, an exclusive focus on how broader political and economic structures and processes interact with household dynamics considering households as one whole can obscure oppressive interactions taking place at household-level, i.e., by silencing gender-relations (Scurrah-Ehrhart, 2007; Razavi, 2009; Bezner Kerr, 2014).

To reach a comprehensive understanding of farmers' agrobiodiversity choices, in the second part of the analysis we attempt to disentangle the processes embedded in local agricultural labour relations by looking at how intra-household power dynamics interact with broader socio-economic changes. Previous research has demonstrated that a large share of the lived experiences and contestation of power takes place at household-level (Agarwal, 1997; Razavi, 2009; Bezner Kerr, 2013; Ravera et al., 2016b). In the Bassari case, men's migration in search for off-farm work and the allocation of a big share of their time to cotton cultivation deepened gender inequalities in household labour-division. Women became increasingly responsible of household's subsistence crops, which added to their already burdensome task bundle of reproductive and care responsibilities. As priorities changed, women had less time available for food preparation. Because the processing and cooking of sorghum, fonio, and Bambara groundnut is time- and labour- intensive, women did not contest the switch to maize, rice, and peanut, which cook faster.

Thus, the decline of Bassari traditional crops show how government policies, broader socio-economic structures, and cultural changes, can interact with labour relations and gender dynamics at household level driving changes in crop portfolios.

Beyond simple narratives: implications for climate resilience in the light of political agroecology

The Bassari case exemplifies how economic factors seem to be more important than climatic ones when driving shifts in crops diversity portfolios, a finding also highlighted in other studies (e.g.,

Labeyrie et al., 2021b). These results underscore that agrobiodiversity dynamics and climate change resiliences/vulnerabilites need to be framed paying attention to political economic structures and the way farmers engage with these processes.

Interpreting the local shift in crop portfolios through contrasting narratives can lead to very different stories. According to the 'mainstream development narrative', the fact that Bassari adopted maize, rice, peanut, cotton, and horticulture can be interpreted as a 'success story', as this narrative privileges a productivist and technology-driven approach to agricultural development. In the phase of climate change, farmers' access to research-bred varieties of exotic crops with short cycles can facilitate their adaptation to the shortening of the rainy season.

Interpreting the shift to exotic crops through an 'agrobiodiversity-based narrative', however, would lead to more critical evaluations. The shift to exotic crops entails a decline of Bassari traditional crops, which can reduce the ability of the local agroecosystem to face future climate shocks. Sorghum, Bambara groundnut, and fonio grow well in poor soils and drought-prone areas and require low levels of fertilization. Moreover, they possess traits well-adapted to the local environment and culture. Beyond entailing a simplification of the local farming systems and diets, the loss of diversity of Bassari traditional crops also narrows the pool of locally available genetic diversity, an important asset for climate change adaptation (Altieri et al., 2015; Bardsley et al., 2018).

Linking the argument back to political agroecology and based on the myriad of drivers affecting Bassari farmers' cropping decisions, it becomes clear that both narratives hide weaknesses. The mainstream development model weakens the resilience of farms by making them more dependent on commodity markets and price volatility (de Roest et al., 2018; van der Ploeg, 2021). In this regard, the current trends in the cultivation of Bassari traditional crops could eventually lead to long-term limited (or mal-) adaptive capacity, increasing agroecosystem's vulnerability to climate. However, agrobiodiversity-based approaches risk reinforcing pre-existing power dynamics at household level and locking small-scale farmers in labour intensive crops. In this regard, gender dynamics and labour relations pose barriers to the transformative potential of agrobiodiversity-based practices.

Both 'mainstream development' and 'agrobiodiversity-based' narratives embody opposite visions of what the future of farming could look like in the Bassari territory. Our research provides an example of the new perspectives that emerge from using a political agroecology framework. Paying attention to the intersectional processes and multiple power dimensions that shape agrobiodiversity dynamics can help move beyond dichotomic academic debates into identifying potential pathways to foster resilience in rural agrarian communities in a climate change context.

Looking at the future: what role will new and old crops and varieties play in south-eastern Senegal?

From an agroecosystem's resilience perspective (Cabell and Oelofse, 2012), the introduction of high-yielding short-cycle varieties of new crops does not necessarily conflict with the maintenance of a diverse portfolio of traditional crops and landraces, as access to a diversity of crop species, varieties, and sources improves smallholder farmers' resilience in the phase of climate

change. Our research, however, highlights that policies and interventions rooted on agro-industrial modes of production resulted in a reduction of the local diversity of traditional crops and landraces, despite their potential fit in the predicted drier climate of the region. Therefore, continuing with research and policy narrowly focused on few commercially or nutritionally relevant crops and varieties, neglecting the diversity of crops and landraces that West African farmers have developed over generations could have irreversible impacts for traditional crop diversity and agroecosystem's resilience. Inversely, alone, traditional crops and landraces cannot fulfil farmers' contemporary aspirations and needs.

With political and research support, political agroecology can provide locally feasible and economically viable alternatives to agro-industrial modes of production, helping to revitalize traditional crop diversity while improving farmers' access to new seeds in more democratic and horizontal ways, thereby supporting local agroecosystem's resilience. For example, in northern Malawi, research supporting farmers' experimentation and horizontal farmer-to-farmer knowledge sharing helped diversify crop and varietal diversity while improving food security, nutrition, health, and decision-making power of household members (Nyantakyi-Frimpong et al., 2016; Bezner Kerr et al., 2019). In western Guatemala, participatory plant breeding boosted the cultivation of traditional crops and landraces through the development of new climate adapted varieties that met farmers' multiple needs (Vernooy et al., 2014). All around the world, farmers' groups and movements are creating alternatives against agro-industrial models of farming and the loss of traditional crop diversity –e.g., through the resistance to genetically modified seeds and the support to farmers' seed systems (Toledo and Barrera-Bassols, 2017; Bottazzi and Boillat, 2021). Crucial to these approaches is considering the complexity of local realities and the inherent contradictions that agrobiodiversity-based methods can pose for gender, labour, and market relations (Bezner Kerr et al., 2019; Marfurt et al., 2023a), as well as the risk that local crops are co-opted by international markets, with unexpected local impacts, as it has been the case of quinoa (Kerssen, 2015; Skarbø, 2015).

In sum, policies or interventions aiming at enhancing Bassari resilience should both, halt (or revere) the decreasing trend of Bassari traditional crops and enable Bassari farmers' access to new climate change adapted varieties. To be successful, this process needs to embrace the complexity of social and politically contested processes, paying attention to whose knowledge is considered legitimate, and putting local communities and their ways of knowing at the center. By documenting not only how agrobiodiversity choices are being transformed, but also the traditional ways of managing this diversity and local resistances, our research contributes to describe alternative ways to manage agrobiodiversity within a political agroecology framework. This entails that farmers re-gain sovereignty, knowledge, and control over their own agroecologies, which can only be done by addressing historical agrarian injustices.

We claim for a reconsideration of research priorities in favour of under-researched crops, like fonio and Bambara groundnut, which have an untapped potential in the light of climate change. Alongside these new research priorities, there should be a shift from top-down centralized agrobiodiversity governance systems towards more inclusive processes, participatory actions and shared decision-making (Méndez et al., 2013; Girard and Frison, 2018).

Chapter 6
Crop biocultural traits shape seed networks: implications for social-ecological resilience in south-eastern Senegal

This chapter corresponds to the article:

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Ge-kol (time to harvest)

It is almost dusk, and she is still in the field,
stooping to harvest yams. She tells me she
will sell them in the market tomorrow because
her sister is sick and needs the money.

Nobody in the village knows the secrets of yam
cultivation as well as she does. The first time we met,
she explained to me that God had given her the gift of
cultivating yams because she could not bear children.

I later learnt that there was a deeper, symbolic value
in cultivating yams, a value that I could only attempt
to grasp; in the Bassari language, the vines of yam
are called *leng* and they have the same root as the
word *aneng* that designates the maternal line.

Abstract

Agroecosystems' social-ecological resilience largely depends on the crop diversity generated and maintained by farmers, which provides insurance against changing environmental and socio-economic conditions. In turn, crop diversity generation, maintenance, and distribution is influenced by seed circulation networks. Thus, patterns of seed circulation can support or constrain households' access to crop diversity, affecting on-farm crop diversity. We aimed at understanding the mechanisms shaping seed circulation and farmers' access to crop diversity by: 1) assessing how crop biocultural traits influence patterns of seed circulation; 2) exploring the connections between household position in the seed circulation network and on-farm crop diversity for different crops. We conducted research in south-eastern Senegal applying crop diversity inventories and a survey to document seed acquisitions for the six local staple crops, which differ in biocultural traits. Household's varietal diversity and household- and community-level network measures calculated for each crop were used to compare seed circulation patterns among crops. Then, we analyzed the association between households' position in the seed circulation networks and households' on-farm crop diversity using generalized linear models. Our research advances two main findings about the importance of seed circulation networks for farmers' access to crop diversity. First, several seed circulation networks operate in the same community and at the same time. Each species circulated differently, which can be explained by crop's biocultural traits. Socio-cultural traits, like the cultural relevance of a crop, and biological traits, like a crop's functional group, affect the patterns of seed circulation. Seed circulation networks that involved external actors, like agricultural extension projects or NGOs, were more centralized than seed circulation networks in which these actors were absent. Second, household's centrality in the network of seed circulation (indegree and betweenness) was generally associated with higher on-farm varietal diversity. However, the factors that determined household's access to seeds differed among crops and variety types. Farmer-to-farmer seed circulation networks are instrumental for the maintenance and distribution of agrobiodiversity and catalyze the introduction of new diversity in the agricultural system. Tensions exist between traditional and new mechanisms of seed sharing, resulting in centralized and unidirectional seed distribution, which might affect the social-ecological resilience of the system.

Key words: crop diversity, local seed systems, seed access, seed exchange networks, social network analysis, West Africa

Introduction

Crop diversity contributes to farming systems' social-ecological resilience[1] (Cabell and Oelofse, 2012) by providing response diversity to disturbance through a pool of possible adaptations (Altieri and Nicholls, 2017; Renard and Tilman, 2019; Labeyrie et al., 2021b). At the plot and landscape levels, cultivating different species and varieties simultaneously and over time fosters ecological heterogeneity, which helps responding to ecological, social, and economic shocks (Cabell and Oelofse, 2012). Importantly, crop diversity is a direct outcome of biocultural interactions[2], including farmers' knowledge and practices that allow the generation and maintenance of a constantly evolving biodiversity contributing to farms' long-term social-ecological resilience (Berkes et al., 2000; Folke, 2004; Reyes-García et al., 2013, 2014).

Researchers have investigated the mechanisms affecting the richness and distribution of crop diversity and farmers' access to this diversity (Jarvis et al., 2008; Leclerc and Coppens d'Eeckenbrugge, 2012; Zimmerer et al., 2019). Among the lines explored, scholars have examined the role of social networks in the generation, maintenance, and diffusion of crop diversity and associated knowledge (Pautasso et al., 2013; Calvet-Mir and Salpeteur, 2016; Labeyrie et al., 2021a). Seed circulation networks are shaped by social forms of organization (Leclerc and Coppens d'Eeckenbrugge, 2012; Labeyrie et al., 2014b) and network structure can support or constrain households' access to crop diversity, increasing or decreasing on-farm agrobiodiversity.

Previous research has tested the existence of a relationship between farmers' position in the seed circulation network and on-farm crop diversity levels. Most studies have documented general flows of seeds and information, not allowing to discern differences between crop species and variety types (Calvet-Mir et al., 2012; Kawa et al., 2013; Díaz-Reviriego et al., 2016; Abizaid et al., 2016). Few studies have considered whether crops and/or varieties might circulate differently depending on their biocultural properties. For example, crop ecology affects seed production and viability and might thus affect seed circulation (Leclerc and Coppens d'Eeckenbrugge, 2012; McGuire and Sperling, 2016). Reproduction type might affect the amount of propagative material that farmers' need or can share –e.g., crops that reproduce vegetatively present a lower multiplication rate and their planting material is less easy to store and transport (McKey et al., 2010). Pollination-type might affect out-farm seed acquisition, as gene flows may challenge maintaining the identity of out-crossing varieties over time (e.g., Allinne et al., 2008, for millet) compared with self-pollinating crops (e.g., rice; Nuijten and Almekinders, 2008). Seed storability can also affect on-farm seed availability (Meikle et al., 2002; McGuire and Sperling,

[1] We adapt the definition of social-ecological resilience 'the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, and identity' (Walker et al., 2004, p. 3) to agroecosystems by defining agroecosystem resilience as the capacity to produce food despite shocks (Cabell and Oelofse, 2012).

[2] Biocultural interactions refer to the dynamic relationship between biological processes and cultural practices, which are deeply intertwined and mutually influential. For crops, these interactions encompass selection, cultivation, consumption and valuation within specific cultural contexts (Maffi, 2012).

2011), as seeds sensitive to weather, pests, or other hazards might need faster renewal, which might boost seed circulation. For example, to minimize seed losses during storage, farmers in Haiti sell legume seeds after harvest and buy new ones at sowing time (McGuire and Sperling, 2016). In the same line, the seed stocks of some crops are more susceptible to be used as food in case of shortage than the seeds of other crops. Other factors, such as commercial value, dietary relevance, and the customary exchange value might also be important to explain the way different crops circulate (Delêtre et al., 2011; McGuire and Sperling, 2016; Thomas and Caillon, 2016). However, with the exception of a study carried out in the Vanuatu archipelago (South Pacific) (Thomas and Caillon, 2016), we know of no analysis considering the potential simultaneous influence of crops biological and socio-cultural traits in explaining seed circulation patterns.

A different research line has focused on customary rules guiding seed flows. This body of research shows that seed circulation is limited by social factors such as ethnolinguistic boundaries in Kenya (Labeyrie et al., 2016), marriage prohibitions in Gabon (Delêtre et al., 2011), or kinship in the Amazonia (Abizaid et al., 2016). While informative, this literature neglects the role of non-community actors. Seeds and related information circulate through networks involving farmers, but also other actors such as governmental and non-governmental organizations, local markets, the private sector, or local, national, or international institutions (Pautasso et al., 2013; Coomes et al., 2015; McGuire and Sperling, 2016). Research in other fields has shown that the type of actors and the relations between actors impact the resilience and sustainability of social-ecological systems (Bodin et al., 2016; Bodin, 2017). However, the impact of actor composition on seed exchange networks has yet to be tested.

Our work combines research insights from these research lines to explore how crops biological and socio-cultural traits relate to farmers' access to seeds. Building on the work of Thomas and Caillon (2016), we conceptualize crops as biocultural objects because they embody the interconnectedness of biological and cultural systems. We hypothesize that different crops might circulate differently, with different seed circulation networks operating within the same community. We further hypothesize that the different seed circulation networks can be (at least partly) explained by crops' biocultural traits, including the constellation of actors that intervene in their seed circulation.

We conducted research in south-eastern Senegal, a region where the agricutural system is mostly rainfed and biodiversity-based. We start by comparing the types of actors involved in seed exchanges and the seed circulation patterns of the six staple crops grown in the area. Then, we analyze the association between households' position in the seed circulation networks and households' crop diversity for each staple crop and their varieties. Finally, we discuss the implications of our results for the social-ecological resilience of smallholder farms.

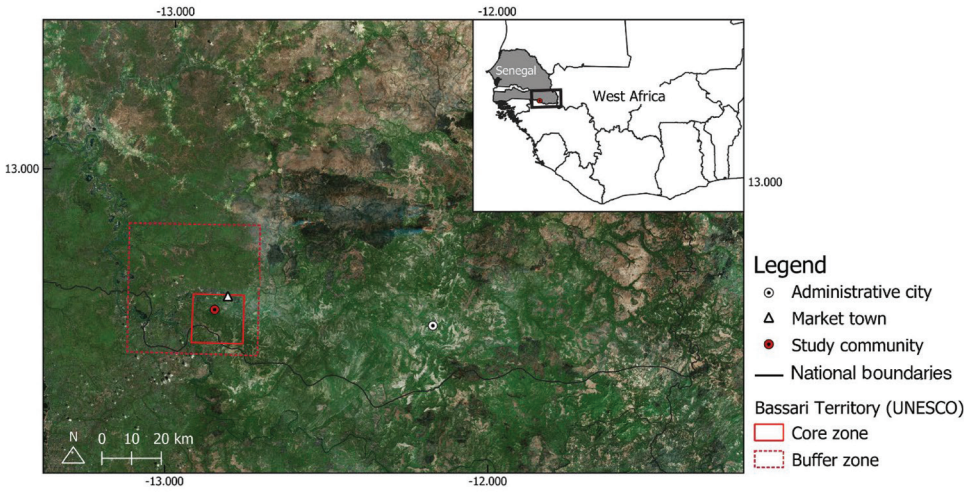

Figure 6.1: Map of the study area.

Case study

Study site

Data were collected in a Bassari village[3] in south-eastern Senegal (Figure 6.1). The altitude in the region varies from 115 to 380 m.a.s.l. and the climate is characterized by a rainy season (approx. June to October) and a longer dry season (ANACIM, 2020). The main administrative centre –Kédougou– and the closest market town –Salemata– are located respectively 90 and 11 km away from the study site. A paved road connects Salemata with Kédougou, but until 2020 access to the administrative city was limited or completely closed during the rainy season. Bassari are the largest ethnic group in the area, where there are also other ethnic groups (e.g., Fula, Coniagui, Dialanké, Malenke). In 2012, UNESCO declared part of the area as a World Heritage site (UNESCO, 2012), called 'Bassari territory' in Figure 6.1.

The main livelihood activity in the area is rain-fed farming, and the bulk of agricultural activities are concentrated during the rainy season and the beginning of the dry season. In the light of climate change, the rainy season is shortening and the frequency and intensity of dry spells are increasing, challenging local farming activities. Agriculture mostly consists of subsistence-oriented cultivation of cereals (sorghum, rice, maize, fonio) and legumes (peanut, Bambara groundnut). Households also sell excess crops in local markets. Cotton is the only cash-crop, and its cultivation is mostly undertaken through contract-farming arrangements with Sodefitex, a former state-owned company that has been increasingly privatized. Most households are

[3] The name of the case-study village is not mentioned to respect anonymity.

largely self-sufficient foodwise, although there is an increasing dependence on commercial rice. Beyond farming, most households also take part in other income generating and subsistence activities such as wage labour, artisanal work, hunting and gathering, palm wine processing, and harvesting of wild edible plants. Livestock keeping is an important way of capitalization.

Bassari farmers adjust to variable soil conditions by diversifying crops and using different management strategies. *Oxenga* are fields in the hills where farmers mostly rotate peanut, Bambara groundnut, sorghum, cotton, and fonio, using few or no chemical inputs (except for cotton). A typical crop rotation[4] lasts 5-6 years, which requires access to different plots. *Eden* are fields in the floodplains, more fertile and intensively cultivated than in *oxenga*. In *eden* there are no crop rotations, fallow periods are short, and farmers use chemical inputs to sustain production. Farmers' cultivate rice in *eden* fields that get inundated during the rainy season, and maize in the rest. In the past, cultural taboos prohibited agriculture next to the river basins, however cultivation in *eden* is now growing. Contrasting with up-hill lands, land in the lowlands starts to be considered scarce by the Bassari. *Enam* are fields around the houses (generally in the hills), managed quite intensively, without rotations, and maintained largely by using organic fertilizers. They are mostly cultivated with maize and minor crops.

As in other locations worldwide (Garine et al., 2018), seed circulation among the Bassari follows traditional social norms, cultural values, and economic rationales expressed through gender, residence, kinship, and age-class[5] relations. The Bassari society is generally characterized by sex-opposed spheres of ritual and economic activity (Nolan, 1986). Men and women independently carry out agricultural activities (e.g., seed selection and storage), although they might help each other during specific moments of the crop cycle. Most crops are gender-specific: cotton and sorghum are mostly cultivated by men, and peanut, Bambara groundnut, fonio, and rice are mostly cultivated by women. Maize is cultivated by men and women. Bambara groundnut and sorghum are 'the' gendered crops par excellence and the basis of *enap*, Bassari staple porridge, which combines women's and men's harvest. Residence is patrilocal (women move to their husband's village), resulting in geographically extensive matrimonial networks. Village residency is a socially structuring factor: age-class system ritual activities (e.g., initiation ceremonies) are performed by groups of neighbouring villages and the organization of communal labour exchange

[4] A traditional crop rotation would be: a newly-cut field –Field A– is planted with Bambara groundnut and/or peanut. The following year, sorghum is planted in Field A, and a second field –Field B– is planted with Bambara groundnut and/or peanut. In the third year, Field A reverts to Bambara groundnut and/or peanut and Field B to sorghum. This alternation continues until the fields are exhausted, then, new fields are opened and the old fields are cultivated with fonio. Nowadays, in rotations sorghum is being replaced by cotton and maize, and Bambara groundnut by peanut.

[5] Age-class (also referred to in literature as 'age-grade') is a highly-structured hierarchic system in which power is held by the elders. Progression in the age-class system entails conducting a series of tasks and rituals, including agricultural common working days (Gessain, 1975; Nolan, 1986). Traditionally, age-class rituals marked the main agricultural seasons and age-class labour pooling was important to sustain the work-intensive Bassari agricultural system (Nolan, 1986). Age-class progression is gendered and there are rigid rules about men/women's roles in ritual and economic activities.

is structured along neighbourhood residency[6]. Indeed, in Bassari language, neighbourhoods are called *andyana*, which translates as 'those with whom I work' (Nolan, 1986). Kinship and matrimonial networks are also important in explaining seed circulation: upon a person's death, the Bassari would traditionally transmit seeds to the niece/nephew from sister-side (Gessain, 1975; Nolan, 1986), although this is now changing towards a system in which men inherit their father/grandfather' seeds and women inherit their mother/grandmother's seeds. Finally, until recently, the age-class was important in structuring Bassari social relationships, tasks, rituals, and communal agricultural work (Nolan, 1986), thus potentially influencing seed circulation.

Besides gender, residence, kinship, and age-class relations, local markets and agricultural extension projects might also shape Bassari seed access. Local markets are mostly attended by women to sell grain or other agricultural or wild-plant products and to buy supplies. Bassari farmers frequent the weekly market in Salemata, and rarely the bigger and permanent market in Kedougou. None of these markets have specialized seed vendors, but seeds are sold by other farmers and re-sellers who bring seeds from bigger markets. Within the study village, three small shops also sell local peanut seeds during the sowing season. In the last decades, there have also been several NGO- or government-based development projects promoting maize, rice, and peanut cultivation through the provision of seeds, chemical fertilizers, and pesticides (Porcuna-Ferrer et al., 2024a).

Biocultural traits and seed management of Bassari staple crops

Bassari staple crops have different agronomic characteristics, cultivation histories and cultural and symbolic functions in the Bassari farming system (Table 6.1).

Sorghum (*Sorghum bicolor* [L.] Moench) is well adapted to semi-arid agronomic conditions, being resistant to drought and heat (Smith and Frederiksen, 2000). Sorghum is one of the oldest crops cultivated by the Bassari, who rarely renew their seed lot, with most households maintaining the same varieties over decades. Exclusively cultivated by men, sorghum is mostly used for household consumption and particularly for the preparation of sorghum beer, a central product in Bassari ceremonial life (Gessain, 1996).

Bambara groundnut (*Vigna subterranea* [L.] Verdc.), an annual legume with a high nutritional value and tolerance to adverse environmental conditions (Mayes et al., 2019), has also been cultivated by the Bassari for a long time and has a strong symbolic and ceremonial importance. Indeed, sorghum beer and Bambara groundnut seeds are the two only products explicitly forbidden to sell by Bassari tradition. Bambara groundnut is mostly cultivated by women, who renew frequently the seed lots due to the difficult storage and high frequency of pest attacks. Like for sorghum, households maintain the same Bambara groundnut varieties over decades.

[6] Bassari neighbourhoods are semi-independent units geographically separated from each other and generally organized according to patrilineal clans. Neighbourhoods have a certain level of independence; each neighbourhood has a chief and neighbourhood boundaries are usually more significant and precise than village boundaries (Nolan, 1986).

Table 6.1: Crops' characteristics.

	Sorghum	**Bambara groundnut**	**Fonio**	**Maize**	**Rice**	**Peanut**
Scientific name	*Sorghum bicolor*	*Vigna subterranea*	*Digitaria exilis*	*Zea mays*	*Oryza sativa*	*Arachis hypogaea*
Biological characteristics						
Functional group	Cereal	Legume	Cereal	Cereal	Cereal	Legume
Type of reproduction	Partially outcrossing	Predominantly self-pollinating	Predominantly self-pollinating	Outcrossing	Predominantly self-pollinating	Predominantly self-pollinating
Storage capacity	High	Low	High	High	High	Low
Socio-cultural characteristics						
Time in the local farming system	Traditional	Traditional	Traditional	Introduced (recently)	Introduced (recently)	Introduced (formerly)
Food use	Staple, traditional dish (*enap*) and sorghum beer	Staple, traditional dish (*enap*)	Staple, mostly for festivities	Staple, modern dish	Staple, modern dish	Sauce, snack
Gendered crop management	Only men	Only women	Mostly women	Women and men	Mostly women	Mostly women
Marketability*	Medium	Low	High	Medium	Medium	High
External support	Low	Low	Low	High	High	Medium

* All crops are mostly cultivated for self-consumption.

Fonio (*Digitaria exilis* Stapf) is a fast-growing cereal well adapted to poor soils and semi-arid conditions (Abrouk et al., 2020). For the Bassari, fonio is a women's crop, introduced at the end of the crop rotation cycle, when the land is exhausted. Fonio is mostly consumed during festivities and, although its sale is not culturally prohibited, economic transactions are rare. Many households only cultivate fonio during the cropping season preceding an important festivity. As a result, seed lots are not stored for a long time within the households. Women typically preserve their seeds by sharing them with other farmers at sowing time and receiving a portion of their harvest afterwards.

Maize (*Zea mays* L.) was introduced in the Bassari territory in the early 1900s by a neighbouring ethnic group. Nowadays, it is strongly promoted by agricultural development projects that supply high yield short-cycle maize varieties and chemical fertilizers. Maize can be cultivated by both men and women, who sow it in fertile and deep soils. Maize is mostly used for household consumption and seems to be replacing sorghum in the Bassari food system, e.g., it has become the main staple in many meals, and its beer is increasingly substituting sorghum beer. Maize seeds are typically stored at home, with granaries predominantly managed by men.

Asian rice (*Oryza sativa* L.) has higher water and nutrient requirements than other local staple crops. Rice arrived to the Bassari territory in the 1900s and was initially cultivated in small areas, but its cultivation has increased in the last 20 years, with the arrival of new high yielding varieties initially distributed by the state and later by development projects, which also distribute herbicides and fertilizers. Rice is mostly cultivated by women and nowadays occupies most floodplains in the case-study village. Although women tend to store their own rice seeds, agricultural extension projects are an increasingly important seed source.

Peanut (*Arachis hypogaea* L.) is a legume domesticated in South America, initially introduced in the Gambia river basin by Portuguese traders (16th century) and cultivated in small quantities until it was promoted by the French colonial government (mid-19th century) and later by post-colonial governments through the creation of state cooperatives and subsidized seeds (Bernards, 2019). Nowadays, although the government subsidize peanut seeds, the Bassari prefer to cultivate their own. Peanuts are mostly cultivated by women for household consumption. Seed lot renewal takes place often, as seeds are very vulnerable to pest attacks. Peanut seeds have important market value and can even be used as an alternative currency.

Methods

Sampling

Data were collected during November 2019-April 2020 and September 2020-June 2021. Fieldwork was interrupted by the Covid-19 pandemic. As Bassari agricultural activities were not strongly impacted by Covid-19, our data can be considered representative of a 'typical year'. The first author lived in the case-study village during the two periods of data collection, which allowed combining qualitative ethnographic research with systematic data collection.

Our sampling unit was the household[7], as many agricultural activities are conducted at that level. We defined the limits of the network as that of the studied community and initially included in our sample all Bassari households in our case-study village. We also included households' interactions with actors outside the village, including other households, NGOs, and market vendors.

We visited each household twice, first to conduct a crop diversity inventory and later to conduct a seed exchange network survey. Both interviews were conducted with all available household members who had cultivated an independent plot during the previous cropping season. Some households were not available for interviews, so our final sample includes 117 households (or 95 % of a total of 123 households in the village).

[7] We define a household as a group of people (normally belonging to the same extended kin group) pooling resources, including exchanging labour without payment and 'eating from the same pot'. Among the Bassari, there are monogamous and polygamous households and it is common that several generations live together. Household members can exchange or sell part of their own harvest, but they have to provide part of the harvest for cooking common daily meals. Intra-household seed exchanges are a common way of seed provisioning.

Data collection

Crop diversity inventories of local staple crops

To characterize crop diversity at the village- and household-levels for the six staple crops, we conducted two village focus group discussions, one with men and one with women, and household crop diversity inventories.

Focus group discussions unravelled the local taxonomy of the staple crops and helped us establish a reference list of variety names known by farmers. Because local farmers often replace or mix their seed stock with same-variety seeds from other farmers, we decided to work at two levels: seed lot and variety. Following Louette and Smale, 2000, we use the term 'seed lot' to refer to a particular physical batch of seeds of a variety that farmers maintain through time without mixing it and that they use to produce next season's crops. We use the term 'variety' to refer to the emic categories identified by farmers as a management unit composed by seed lots of the same kind, corresponding to plants with similar phenotypic characteristics according to farmers' perspective (Louette and Smale, 2000). While acknowledging that introduction of crop varieties is a dynamic process and categorization not always exclusive, we adopted the 30 years threshold proposed in the literature to distinguish between variety types (Calvet-Mir et al., 2011; Tardío et al., 2018).

We classified varieties in three groups based on farmers' reports about the period and actors introducing them: 'farmer varieties', 'introduced farmer varieties', and 'non-farmer varieties'. *Farmer varieties* are varieties selected, reproduced, and kept by farmers and which have been in the local farming system for more than 30 years (also referred to as 'landrace' or 'heirloom varieties').[8] *Introduced farmer varieties* are varieties introduced through farmer-to-farmer seed exchange within the last 30 years. *Non-farmer varieties* refer to varieties developed by professional plant breeders, which have recently arrived to the community through agricultural extension projects. For each variety, during the focus group discussions, we documented the names most frequently used by farmers, the existence of any synonyms, and varieties' characteristics (e.g., maturity cycle, colour, size, uses).

To obtain household's crop diversity inventories, we asked farmers to list all the staple crops they had cultivated during the previous growing season. For each staple crop, we asked them to estimate the surface cultivated in 'cordes' (1 corde = 0.25 hectares) and to provide the local names of all the cultivated varieties of each crop. We insisted that respondents listed all varieties grown, including those represented by a very limited number of individual plants. To ensure consistency in naming, we asked follow-up questions about the variety characteristics, which we then compared to our reference lists elaborated during focus groups. When farmers finished listing, we used the reference lists to ensure that we captured all crops or varieties grown in their fields.

[8] We use the term 'farmer varieties' instead of the most common term 'landraces', to emphasize that our classification is based on farmers' reports.

Seed network survey

To capture the full diversity of local staple crops cultivated by the household, we conducted a survey with all male and female adults living in the household who had cultivated a plot during the cropping season before fieldwork. For the analyses, individual data (n = 258) were aggregated at household level (n = 117).

The survey had three sections: (1) farmers' individual information (i.e., age, gender); (2) household information (i.e., number of adults in the household, age and gender of household head(s), cultivated area for each staple crop, number of market assets owned by the household), and (3) source of each cultivated seed lot for: i) the most recent cropping season, ii) the most recent external acquisition (i.e., different than self-produced), and iii) the very first external acquisition (i.e., first time they obtained a particular variety). For each seed lot and variety cultivated, we asked for the number of years since the first acquisition.

For each seed transaction, we also documented: i) its nature (i.e., exchange, purchase, credit, gift/inheritance); ii) seed giver type (i.e., household within the village, household from outside the village, project/NGO, market vendors from outside the village, other). Market vendors from the village were considered as households within the village and market vendors from outside the village were classified as market vendors; iii) the location of the seed giver vs. the receiver (i.e., within neighbourhood, different neighbourhood, outside village, and outside Bassari territory); iv) existing social relation(s) between the seed giver and receiver (i.e., age-class, neighbours, friends, kinship, other).

Data analysis

Seed circulation networks of local staple crops

Seed transaction events recorded in the seed network survey were aggregated by constructing six seed circulation networks from edge lists, one per crop species. Each edge list contained as many rows as documented seed transactions and two columns: the household that received the seed and the actor who gave the seed. Since our interest was on seed acquisitions outside the household, seed self-production and intra-household seed transactions were excluded from the edge lists.

For each network, we calculated seven network-level measures and three node-level centrality measures (Borgatti et al., 2018). The indegree metric was split into four different metrics according to seed giver type (see Table 6.2 for details). Data analysis was done using R version 4.1.2 (R Core Team, 2021). All networks were represented and network measures calculated using the R package 'igraph' version 1.2.7 (Csardi and Nepusz, 2006). For network visualization, we considered three types of nodes: households, projects/NGOs, and market vendors. Ties between the nodes are directional, not weighted, and represent the different seed transactions. To compare the networks across different crops, we conducted an independence test (Pearson's chi-square test and when not possible, Fisher's exact test) concerning crop species and seed transaction characteristics (i.e., social relationship, actor type, distance to seed sources, and seed transaction type), and post-hoc tests to assess individual frequency deviations. For the social relationship involved in the seed transaction,

Table 6.2: Network-level and node-level measures calculated to describe the seed circulation networks of each of the local staple crops.

Measure	Definition
Network-level measures	
Size	Total number of nodes
Density	Ratio between the number of existing versus possible links
Reciprocity	The proportion of mutual connections in a directed graph
Modularity	The share of internal links in the subgroups from the expected number of links if the distribution was random. Members of the same subgroup (also called 'communities' in social networks' literature) exchange more with other members of the same subgroup than with no-members (compared to what we would expect if seed circulation was random)
Number of independent components	Number of connected subgraphs where all actors are directly or indirectly connected with other actors of the same subgraph but not with actors belonging to another subgraph
Indegree centralization	The sum of differences between each node's indegree and the one having the maximal indegree (normalized by its theoretical version in the case of an in-star graph)
Outdegree centralization	The sum of differences between each node's outdegree and the one having the maximal outdegree (normalized by its theoretical version in the case of an out-star graph)
Node-level measures	
Indegree	The number of incoming ties, which in our case represents the number of seed transactions in which the node was considered as a seed receiver. We classify indegree according to giver type (i.e., seed transactions received from households within the village, households from outside the village, projects/NGOs, and market vendors from outside the village). Indegree is not weighted
Outdegree	The number of outgoing ties, which in our case represents the number of seed transactions in which a node was mentioned as seed giver. Outdegree is not weighted
Betweenness	Number of times a node is at the shortest path in transactions between two other nodes. The shortest path is calculated based on the number of nodes that separates the different actors. Betweenness is not weighted

when seed giver and receiver shared several ties, we only considered the strongest one according to our ethnographic understanding of the case-study area. Analyses were carried out using the package 'stats' version 4.21.

Relation between household centrality and varietal diversity

We calculated households' varietal diversity for each main crop using data from the crop diversity inventories. For each household and crop, we generated four variables capturing the total number of cultivated (i) farmer varieties; (ii) introduced farmer varieties; (iii) non-farmer varieties, and (iv) all varieties (i.e., the sum of all types).

The correlation between a households' varietal diversity and its position in the seed circulation network was only calculated for households within the case-study village. To estimate the association, we fitted several Poisson generalized linear models (GLM) with a logarithmic link using the 'stats' package version 4.1.2 (R Core Team, 2021). Since centrality measures (i.e., indegree, outdegree, betweenness) are not independent, their individual effects might be masked if added in the same model. Therefore, we ran different models for each staple crop (6), variety type (4), and centrality measure (3), adding up to 63 models as sorghum, Bambara groundnut, and fonio did not have 'non-farmer varieties'. In our models, we sequentially used the four varietal diversity variables (i.e., all varieties, farmer, introduced, and non-farmer varieties) as outcome and network measures (i.e., indegree, outdegree, betweenness) as explanatory variables. We ran distinct models for indegree, outdegree and betweenness, while considering as controls several additional factors previously suggested to affect the level of crop diversity grown by the household –i.e., number of adults, percentage of female adults, age of the household head, cultivated surface per main staple crop, and household's economic status (Table 1s in Appendix 4). Households with missing data in some explanatory variables were removed from the corresponding models and therefore the sample sizes considered for the final models were smaller than the number of households' actually growing each staple crop.

We conducted a backward model selection process to assess the best models according to the Akaike information criterion (AIC). For each staple crop and variety type, we built 3 complete models, each one including a different centrality measure and all considered explanatory variables (number of varieties and control variables; see Table 1s in Appendix 4). The backwards model selection process removed explanatory variables one by one, minimizing AIC values, until we got the best fitted model. Even though initial complete models have the same predictors except the centrality measures, the models after the backwards selection process present different relevant predictors, as all variables without a statistically significant relation with the varietal diversity maintained by the households ($p > 0.1$) were removed from the final model. Final models only include statistically significant relations.

Results

Diversity of local staple crops in Bassari fields

Crop diversity richness and distribution largely varied across households. Peanut, maize, and rice were the most cultivated crops by the 117 households interviewed, often occupying large surfaces. Fonio and sorghum were also cultivated in relatively large surfaces, but by fewer households. Bambara groundnut was cultivated by most households, but in very small surfaces (Table 6.3).

At the village level, we identified 12 varieties of peanut, 10 of maize, 9 of rice, 6 of sorghum, 4 of fonio, and 4 of Bambara groundnut. On average, households maintained 1-2 varieties for each staple crop, except for peanut, for which most households kept more than two varieties. For sorghum, Bambara groundnut, and fonio, farmer varieties predominated and non-farmer varieties were not reported. Introduced farmer varieties and non-farmer varieties predominated for maize

Table 6.3: Crop diversity maintained in Bassari fields, per crop.

	Sorghum	Bambara groundnut	Fonio	Maize	Rice	Peanut
Number of households in the case-study village that cultivate the crop (total, %)	79 (67.52)	98 (83.76)	50 (42.73)	115 (98.29)	102 (87.18)	116 (99.14)
Mean surface cultivated per household (in cordes)	0.99	0.52	1.07	1.84	1.55	2.14
Number of varieties (total in the community, mean per household)	6 (1.33)	4 (1.32)	4 (1.02)	10 (1.58)	9 (1.34)	12 (2.53)
Farmer varieties (total , % of households that grow them)	5 (100)	2 (82.98)	3 (85.37)	3 (20)	3 (1.01)	3 (87.93)
Farmer introduced varieties (total, % of households that grow them)	1 (2.74)	2 (37.23)	1 (17.1)	5 (68.69)	4 (69.7)	8 (91.38)
Non-farmer varieties (total, % of households that grow them)	0 (0)	0 (0)	0 (0)	2 (43.47)	2 (55.6)	1 (6.03)

and rice. Peanut non-farmer varieties were rare, and households mostly grew peanut introduced farmer varieties and farmer varieties (Table 6.3). For each crop, few varieties were cultivated by most households and most varieties were cultivated by only one or two households.

Networks of seed circulation of local staple crops

Socio-demographic characteristics of seed circulation

We found statistically significant differences among seed transaction characteristics per crop: distance to the seed source ($\chi^2 = 151.16$, df = 30, $p < 0.05$), social relationship ($\chi^2 = 145.77$, df = 35, $p < 0.05$), seed transaction type ($\chi^2 = 445.26$, df = 20, $p < 0.05$), and type of actor mobilized to acquire seeds ($\chi^2 = 88.05$, df =15, $p < 0.05$). Seed lot and variety age also differed between crop species ($p < 0.05$).

For all crops, most seed acquisitions took place within the case-study village (Figure 6.2C). Sorghum seed acquisitions had the lowest geographical spread, with most seed acquisitions taking place within the neighbourhood (70.59% of seed acquisitions, $p < 0.05$) (Figure 1s in Appendix 4). Bambara groundnut and peanut seed acquisitions had the widest geographical spread ($p < 0.05$), with seeds flowing in from villages within the Bassari territory, mostly within Senegal (30%), but also from Guinea (7%). Peanut seed acquisitions within the village (but outside the neighbourhood) were larger than for other crops ($p < 0.05$), and acquisitions from outside the Bassari territory were also more frequent than for other crops (3.04% taking place outside the Bassari territory), but this difference was not statistically significant ($p > 0.05$).

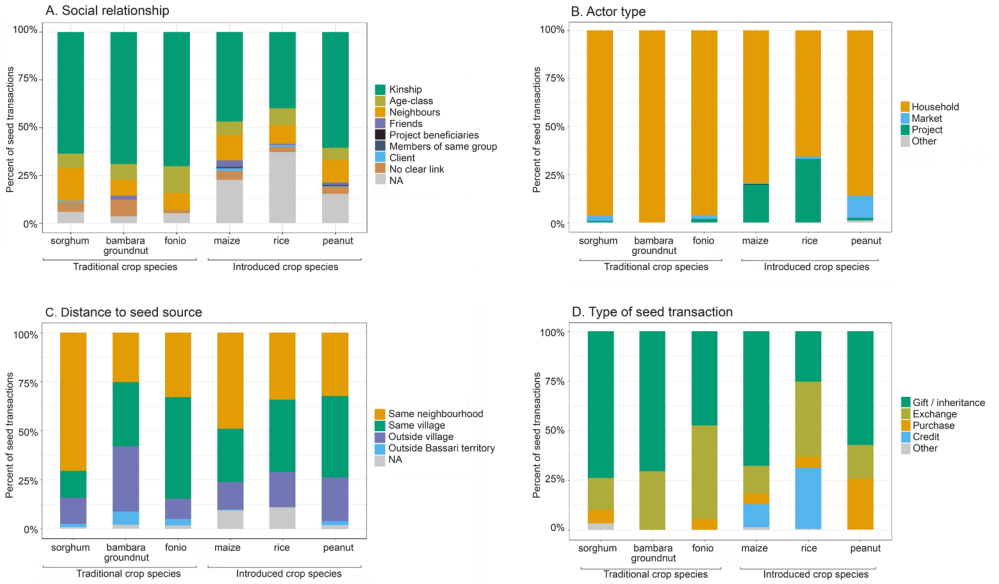

Figure 6.2: Seed transactions characteristics (in %), per crop. In A, when giver and receiver shared several ties, only the strongest one was considered. From higher to lower strength: kinship, age-class, friends, neighbours, project beneficiaries, members of the same group, client.

Most households mobilized kinship relationships to acquire seeds. However, kinship relations were less important for acquiring maize (46.7% of seed acquisitions) and rice seeds (39.9%) than for other crops (> 60% of seeds acquisitions, $p < 0.05$). The second and third most important ties mobilized for seed acquisition were neighbours (10% of the cases) and members of the same age-class (7%). Other types of ties, such as friendship or same group membership (e.g., church, sports, or women groups), were rarely mentioned (Figure 6.2A).

Farmers acquired seeds from a diversity of actors. Irrespectively of the crops, most seeds were acquired from other farmers. Other farmers were the predominant providers of Bambara groundnut (100%) and sorghum (96%) seeds, and less dominant in rice seed acquisitions (65.7%, $p < 0.05$). For maize and rice, projects/NGOs played a more significant role as seed providers compared to other crops (19.5% and 33.1% respectively, $p < 0.05$). Peanut was the only network where seed acquisitions from market vendors were important (11.5%, $p < 0.05$) (Figure 6.2B).

We found differences in transaction types among crop species. Gifts/inheritance and exchanges were the predominant ways of acquiring seeds for all crops. Seed purchases were reported sporadically (approx. 5% of seed acquisitions) for all crops except for Bambara groundnut, for which no seed acquisitions involving monetary transactions were reported. Conversely, peanut was the only crop for which purchase (from both market vendors and other households) represented 25.7% of seed acquisitions ($p < 0.05$). Maize and rice were the only crops for which credit from projects/NGOs was a common way of sourcing seeds (in 11.36% and 30.6% of seed acquisitions, respectively) (Figure 6.2D).

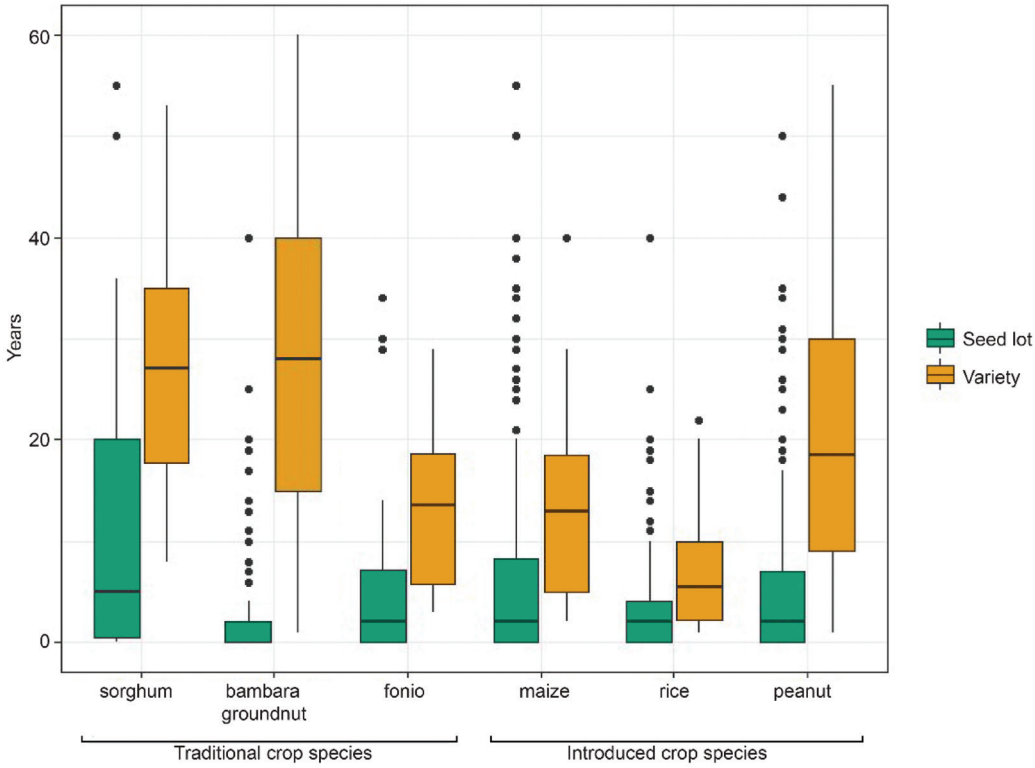

Figure 6.3: Number of years that each seed lot and variety has been kept in the household. Calculated based on the most recent seed transaction that each household did to renew a seed lot or to acquire a new variety.

Seed lot renewal rate differed between crop species. Bambara groundnut, peanut, rice, and fonio had the highest seed lot renewal rates (mean seed lot age < 6 years). However, the difference in seed lot age was only statistically significant for Bambara groundnut (mean seed lot age = 2 years; $p < 0.05$). Sorghum seed lots were renewed less often than seed lots from other crops (mean seed lot age = 11 years; $p < 0.05$). Sorghum and Bambara groundnut varieties were the ones kept in the households for the longest time (mean variety age = 28 years; $p < 0.05$) and rice varieties were the most recently acquired ones (mean variety age = 7 years; $p < 0.05$) (Figure 6.3).

Finally, we found gendered differences in seed circulation. Women were mostly involved in Bambara groundnut, fonio, rice, and peanut seed circulation, and men played a more prominent role in sorghum and maize seed circulation (Table 6.4).

Seed network structure and composition

We found different seed circulation patterns among different crops. In terms of network composition, seeds were mostly acquired from households. Projects/NGOs only played an important role in the maize and rice networks. Market vendors were relevant for peanut seed acquisitions (Figure 6.4).

Table 6.4: Descriptive characteristics of seed circulation networks, per crop. Sample sizes: sorghum (n = 79 households), Bambara groundnut (n = 98), fonio (n = 50), maize (n = 114), rice (n = 102), peanut (n = 116).

	Sorghum	Bambara groundnut	Fonio	Maize	Rice	Peanut
Socio-demographic characteristics						
Receivers' age: mean (min-max)	50 (26-76)	45 (16-78)	46 (19-71)	48 (24-86)	43 (12-86)	44 (14-86)
Receivers' gender (% of women)	27.73	99	79.31	39.82	86.33	93.39
Seed circulation network measures						
Size	107	173	61	167	119	210
Density	0.010	0.007	0.016	0.008	0.013	0.010
Reciprocity	0.055	0.010	0.036	0	0.011	0.063
Modularity	0.832	0.767	0.809	0.719	0.630	0.566
Number of independent components	17	17	11	17	3	3
Indegree centralization	0.027	0.034	0.034	0.034	0.038	0.053
Outdegree centralization	0.046	0.063	0.068	0.155	0.216	0.105

Seed circulation networks varied in size among crops, with peanut showing the largest (210 nodes) and fonio the smallest network (61 nodes). All networks had low densities, i.e., low number of connections or ties (from 0.007 for Bambara groundnut to 0.016 for fonio), and low reciprocity (from 0 for maize to 0.063 for peanut), meaning that farmers giving or selling seeds rarely got back seed of the same crop from the same person (Table 6.4).

All networks presented relatively low indegree centralization indices (from 0.027 for sorghum to 0.053 for peanut), meaning that there was not a single actor concentrating most seed acquisitions. Outdegree centralization indices showed a higher variation among crops (from 0.046 for sorghum to 0.216 for rice), suggesting that seed sourcing is more concentrated for certain crops than for others. For maize, rice, and peanut, projects/NGOs and market vendors were central actors in terms of seed sourcing, whereas for sorghum, Bambara groundnut, and fonio, seed sourcing was less concentrated (Table 6.4).

In all the networks, we found positive modularity scores (from 0.566 for peanut to 0.832 for sorghum), indicating the presence of subgroups within the networks. Modularity scores were higher for the sorghum, Bambara groundnut, fonio, and maize networks than for the rice and peanut networks (Table 6.4). Concerning independent components, rice and peanut networks had fewer independent components than networks from other crops, implying that most actors were

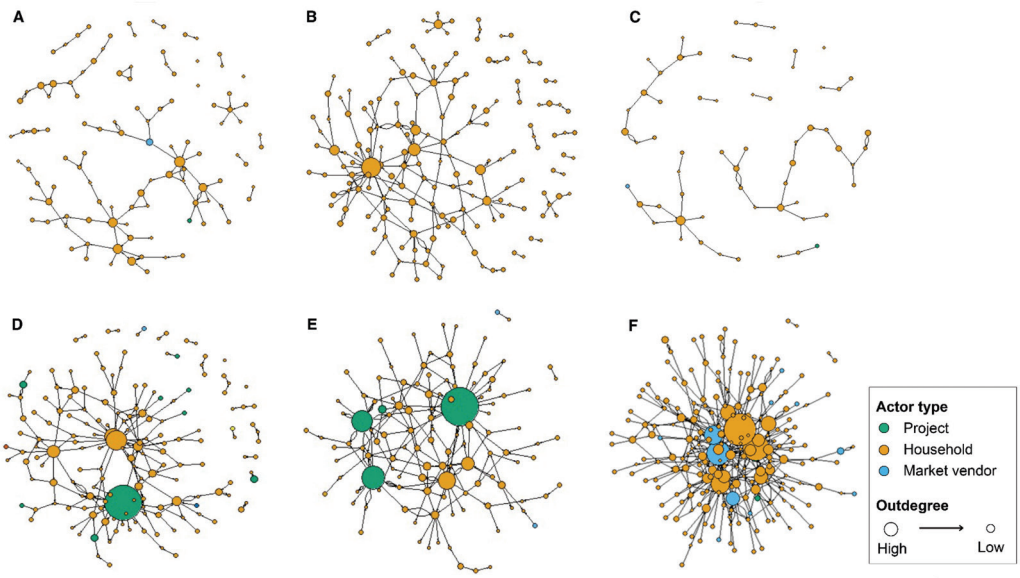

Figure 6.4: Seed circulation networks per crop (Fruchterman-Reingold representation). (A) Sorghum, (B) Bambara groundnut, (C) fonio, (D) maize, (E) rice, and (F) peanut.

connected with each other (for both crops the main component comprised > 90% of actors). The most fragmented network was that of fonio, with 11 independent components, the main one concentrating only 31.15 % of network actors, followed by sorghum, Bambara groundnut, and maize, with 17 independent components each, the main one containing 55.14 %, 71.67 %, and 79.64 % of actors, respectively.

Households' centrality and varietal diversity

Overall, households' varietal diversity was associated to different centrality measures, depending on the crop species and variety type. Across models, household indegree and betweenness most consistently showed statistically significant associations with varietal diversity. Household's outdegree does not appear in the final models because it was not associated in a statistically significant way to varietal diversity for any crop. Cultivated surface, age of the household head, households' economic status, and the number of adults in the household were positively associated with on-farm varietal diversity (Table 6.5).

All varieties

Household's indegree showed a positive and statistically significant association with the total number of varieties cultivated by a household ('all varieties', Table 6.5; Figure 2s in Appendix 4). Household's indegree from households within and outside the village (but not indegree from

Table 6.5: Generalized linear model results. Associations between households' centrality in different crop networks and the household's varietal diversity. Only associations statistically significant are shown. Sample sizes: sorghum (n = 79 households), Bambara groundnut (n = 98), fonio (n = 50), maize (n = 114), rice (n = 102), peanut (n = 116).

		Outcome variables			
Crop	**Explanatory variables**	**All varieties**	**Farmer varieties**	**Introduced farmer varieties**	**Non-farmer varieties**
Indegree (IN), final models					
Sorghum	IN households' village	7.29e-05***	0.000215***		
	IN households' outside village	0.0502+	0.080072+		
Bambara groundnut	IN households' village	0.0747+	0.0423*		
	Cultivated surface			0.0174*	
Fonio	IN households' village	0.00706**	0.0258*		
	IN households' outside village	0.06935+			
	Cultivated surface			0.043488 *	
Maize	IN households' village	3.99e-05***		3.83e-05***	
	IN projects/NGOs			0.08508+	4.59e-05***
	Household head age group				0.0248*
Rice	IN households' village	0.0521+			0.04485*
	IN projects/NGOs				0.00315**
	Cultivated surface	0.0768+		0.04092 *	
Peanut	IN households' village	3.13e-06***		2.54e-06***	
	IN households' outside village	0.0946+		0.0562+	
	IN projects/NGOs				1.35e-05***
Betweenness (BET), final models					
Bambara groundnut	Cultivated surface	0.0295*	0.000818***	0.0174 *	
	Household economic status		0.085400+		
Fonio	Cultivated surface	0.0145*	0.0814+	0.043488 *	
Maize	BET			0.0722+	
	Cultivated surface	0.0707+			
	Household head age group				0.0394*
Rice	BET			0.03969*	
	Cultivated surface	0.00721**			0.022007*
Peanut	Cultivated surface	0.0425*		0.0102*	
	Household economic status				0.0711+
	Household adults				0.0925+

p-values: +, *, **, *** at the 0.1, 0.05, 0.01 and 0.001 levels.

Projects/NGOs) were significantly related to sorghum, fonio, and peanut varietal diversity. Contrastingly, connections outside the village did not have an important contribution to Bambara groundnut, maize, and rice household's varietal diversity. For these crops, diversity was only related to the indegree from households within the village (Table 6.5).

Farmer varieties

We found a positive and statistically significant association between the diversity of farmer varieties grown by the household and indegree from households from inside the village for sorghum, Bambara groundnut, and fonio. Only for sorghum the same association was found between households' diversity of farmer varieties and indegree from households outside the village (Table 6.5). We did not find any statistically significant association between the number of farmer varieties grown and household's indegree in the maize, rice, and peanut networks.

Introduced farmer varieties

Households' diversity of maize, rice, and peanut introduced farmer varieties was associated with households' indegree and/or betweenness. This association was significant when considering indegree from households within the village for maize and from households within and outside the village for peanut. For maize and rice, household's varietal diversity of introduced farmer varieties was also associated to household's betweenness.

Non-farmer varieties

Household's diversity of maize, rice, and peanut non-farmer varieties was positively and significantly associated to household's indegree from projects/NGOs. Only for rice, the households' diversity of non-farmer varieties was also associated with household's indegree from other households within the village.

Discussion

The main result of our work is that several seed circulation networks operate in the same community and at the same time. This can arguably be explained by differences in the factors determining household's access to and maintenance of seeds of various crops and varieties. This result advances two central arguments about the importance of seed circulation networks for access to crop diversity and, therefore, for the social-ecological resilience of farming communities. First, seed circulation is shaped by crops' and varieties' biocultural traits and second, households' centrality in the seed circulation network is related to on-farm crop diversity. Before discussing the main results, we note that our results suffer from several potential shortcomings.

Limitations

First, these seed circulation networks aggregate seed transactions taking place at different moments in time and do not consider that the timings of interactions differ across crops. While this method allows us to capture the origin of seeds cultivated nowadays, it could contribute to mask the contemporary

mechanisms driving seed circulation (e.g., hampering the identification of seed donor-hubs). Research considering only the most recent seed acquisitions could disclose mechanisms at play that were blurred by our methodological choice. Future research should conduct diachronic analysis to assess how seed circulation changes through time and the possible role of external actors in shaping these changes.

Second, we constructed the networks aggregating individual data at household level. However, taking the household as a unit of analysis does not allow to quantitatively assess the importance of some key biocultural variables, such as gender, for seed access and seed network structure. Previous research has shown the importance of intra-household dynamics when studying seed access, highlighting diversity within the household (Wencélius et al., 2016). In this line, future research should look at the relationship between individual farmers' centrality in the seed circulation network and the agrobiodiversity they manage, which might show important factors now masked by our household analysis.

Third, the paper has focused on the effect of households' position in seed acquisition networks for cultivated diversity, leaving aside impacts of other factors included only as control variables. We acknowledge that other variables beyond the ones considered in this study could also influence households' position in the network and on-farm diversity (e.g., diversity of source types and distance to source type).

Fourth, our classification of varieties is based on farmers' reports. Previous research has shown that non-farmer varieties provided by extension services are frequently acquired by farmers through peer-to-peer seed circulation (Teeken et al., 2012; Labeyrie et al., 2014a). As a result, these varieties often end up being perceived as farmer varieties by farmers. In our study, this may have led to an underestimation of the number of non-farmer varieties reported, particularly concerning peanut. Despite the long history of peanut variety improvement in Senegal, our inventory only documented one non-farmer variety.

Fifth, our analysis treats each crop as independent; however, a more comprehensive approach could adopt a relational perspective that views crops and seed exchange networks as components of a complex system. Future research could explore potential links between the diffusion of different crops and varieties. This could involve investigating whether crops that play a similar role in the agroecosystem (e.g., that occupy a similar position in the crop rotation) circulate together or through the same networks.

Seed circulation is shaped by crops' biocultural traits

Our findings suggest that seeds from different crops do not circulate in the same way because crops differ on their biocultural traits. Previous work has shown that crops' biological characteristics influence seed production, viability, and availability (Ellen and Platten, 2011). Seed circulation is also shaped by social relations, cultural rules, and symbolic values associated with crops, which guide farmers' practices like selection, management, storage, and uses (Delêtre et al., 2011; Leclerc and Coppens d'Eeckenbrugge, 2012; Labeyrie et al., 2016). Moreover, human history might also affect the type of actors involved in seed circulation and the geographic distribution of crop diversity (van Etten, 2006).

Our results add to previous studies highlighting that, even within a village, seed acquisition networks vary across crop species, arguably because of differences in crops' biocultural traits. For example, Bambara groundnut's network is larger, has lower density, lower modularity, and wider geographical spread than other traditional Bassari crops, showing that households participate more actively in exchanging, giving, and acquiring Bambara groundnut than sorghum or fonio seeds. Our ethnographic understanding suggests that this is at least partly related to the renewal rate of seed lots, which is connected to legume's seed storage qualities. Bambara groundnut (and peanut) seeds are highly vulnerable to pest attacks, which forces farmers to frequent seed lot renewal. However, crop biology alone does not suffice to explain seed network structure, as demonstrated by differences in seed circulation between the two legumes. The peanut seed circulation network was the largest, best connected, most broadly spread, and most reciprocal of all the seed networks studied, which might be related with the specific historical circumstances of its cultivation.

The commercial production of peanuts for export was promoted by the French colonial regime in the 19th century and by post-colonial governments after Senegal's independence (1960). Although peanuts are no longer the main focus of national policies and nowadays Bassari mostly cultivate peanuts for self-consumption, peanuts continue to be largely acquired through trade and are even used as alternative currency (mostly by women). Peanut abundance in local markets discourages farmers from keeping their own seed, as they know that, in case of need, they will find seed at the market with relative ease. Being widely adopted by the Bassari in the last century, peanuts are less rooted in the local culture than traditional crops and are therefore less subject to cultural rules and norms guiding seed circulation. In contrast, Bambara groundnut seeds bear an important cultural and symbolic value in the local community and circulate in a more restricted way, as shown by the higher number of subgraphs within the seed circulation network. Sorghum provides another good example of how social norms and cultural values restrict the circulation of seeds of traditional crops. Sorghum is an important crop for Bassari ceremonial life and Bassari men's identity. Its seeds circulate mostly within men living in the same neighbourhood, which in the case-study village coincides with members of the same patrilineage, showing the importance of descent and alliance for access to sorghum seeds.

Among the Bassari, the circulation of seeds of traditional crops is particularly embedded in kin, gender and age-class networks. This result is in line with previous research that describes seed circulation as embedded in pre-existing social structures and connected to farmers' social identity (Leclerc and Coppens d'Eeckenbrugge, 2012; Labeyrie et al., 2014b). For example, as in other small-scale societies (Howard, 2006; Díaz-Reviriego et al., 2016), Bassari women play a more important role in household seed provisioning than men, conferring them social status and cultural recognition. They also play an important role in the maintenance of communal social relations, household food security, and generally in caregiving. However, there are also gender-related social differences in seed circulation networks. For example, sorghum seeds are traditionally considered 'the' men crop, and mostly circulate among men.

The actors involved also influence seed flows and the structure of seed circulation networks. Agricultural development agendas and research priorities have historically prioritized the most profit-

able crops (e.g., peanut production for export during colonial and early post-colonial times) or cereal crops with high yields, important for the country's food security strategy, i.e., rice and maize (Porcuna-Ferrer et al., 2024a). Consequently, agricultural extension projects, NGOs, and local markets have also made available seeds of these crops. According to our work, when external actors play a prominent role, seed circulation networks tend to have higher centralization indices. For example, for introduced crops (i.e., maize, rice, and peanut), projects/NGOs and market vendors play a relevant role, and fewer actors concentrate more seed sourcing, which risks reinforcing or creating (new) power dynamics and structural inequalities in the local communities.

In the absence of longitudinal data, it is difficult to assess trends in the coexistence of different seed circulation networks. However, based on our data, we interpret the effect of agricultural extension projects and NGOs in seed circulation in two complementary ways. First, project/NGO-interventions result in centralized seed diffusion models, which might displace decentralized traditional mechanisms/institutions, like kinship or age-class that have secured access to seeds for generations, and create new social networks, that increase the centrality of farmers supported by projects/NGOs or extension services (Isaac et al., 2021). The substitution of traditional sources by new institutional sources could lead to overcentralized networks, potentially constraining local communities' social-ecological resilience (Pelling and Manuel-Navarrete, 2011; Cretney, 2014). Broader socio-economic pressures leading to the rapid transformation of smallholder farming systems and to the weakening of traditional systems of seed sharing also affect how biocultural factors shape seed circulation networks. Local cultivation of sorghum, fonio, and Bambara groundnut is in recession and farmers increasingly rely on NGOs/projects to acquire seeds of newly introduced crops. Market integration, which locally started with the expansion of peanut cultivation in the 1900s and has exploded since the 2000s with the arrival of NGOs, and agricultural development projects that promoted maize and rice cultivation have largely contributed to traditional crop abandonment (Porcuna-Ferrer et al., 2024a). We show that the networks of traditional crops have high levels of fragmentation, small size, and low densities which reflects a high proportion of isolated farmers and a small number of possible seed exchanges. This reduced circulation of seeds increases network fragility, potentially limiting network's capacity to support crop diversity.

A second interpretation of the effect of projects/NGOs in seed circulation refers to their integration in traditional networks. Traditional networks of seed circulation have a high adaptive capacity to channel seeds of new crops. In the theory of change behind the African Green Revolution, farmers' des-centralized seed systems were expected to be gradually replaced by 'formal' centralized ones (Scoones and Thompson, 2011; Westengen et al., 2023). However, among the Bassari, as it has been the case in several locations worldwide, linkages and interdependencies between centralized and des-centralized seed systems have developed (Almekinders and Louwaars, 2002; McGuire and Sperling, 2016). Despite being relatively 'new' crops in the Bassari farming system and strongly supported by development agendas and the official seed sector, maize and rice substantially circulate household-to-household, suggesting that farmers draw on the strengths of the different seed acquisition systems. Still, the broader socio-economic dynamics mentioned earlier urge for caution when assessing the benefits of co-existing forms of seed circulation.

From an agricultural development perspective, the question is how to improve farmers' access to high-quality adapted seeds without breaking the tightly connected relationships that have traditionally played a pivotal role for the resilience of smallholder farmers (Haider et al., 2020). In this regard, our data supports previous research that emphasizes the importance of moving beyond the dichotomy of 'formal/centralized' versus 'informal/decentralized' seed circulation in order to effectively understand and support farmers (McGuire and Sperling, 2016; Westengen et al., 2023). It also highlights the need to assess existing seed circulation networks when devising any intervention (Abay et al., 2011).

Households' centrality in the seed circulation network affects access to crop diversity

Our results show that household centrality in the network of seed circulation is generally associated with on-farm varietal diversity. Previous studies have tested this association, finding contrasting results (Calvet-Mir et al., 2012; Kawa et al., 2013; Abizaid et al., 2016; Díaz-Reviriego et al., 2016). Our results suggest that such contrasting results might just reflect the fact that there is not a single measure of centrality that explains on-farm diversity for all the crops and variety types. Indeed, owing to the specific crop biocultural traits guiding seed circulation, different centrality measures can explain different aspects of access to crop diversity.

As Kawa et al. (2013) and Abizaid et al. (2016), we did not find an association between being an important seed provider (i.e., having a high outdegree) and on-farm varietal diversity. However, we found that the type of actors mobilized for acquiring new seed (indegree types) and the level of household intermediation in the seed circulation network (betweenness) were differently associated with household's varietal diversity, the association depending on the crop and variety type. This finding suggests that household's access to different crops and variety types might depend on its ability to mobilize different types of relations. Access to farmer varieties of traditional crops is best granted through farmers' personal network, whereas households with a higher level of intermediation in the network will hold a more privileged position to access newly arrived varieties, and households that can interact with market-logics and projects/NGOs will probably have better access to non-farmer varieties. Our findings also point to the importance of the socio-economic status of the household for accessing crop and varietal diversity. Specifically, access to land affects cultivated diversity for all crops and most variety types. Household size, age of the household head, and household' financial resources all played an important role favouring access to diversity for certain crops and variety types. These results are in line with previous research that point to wealth as a key structuring factor of seed circulation (Wencelius et al., 2016).

From a social-ecological resilience perspective, farmer varieties are an important reservoir of biocultural memory, as farmers have selected them over generations for their fit to local natural and management conditions. Seeds often circulate together with knowledge about their characteristics, qualities, and management practices (Calvet-Mir et al., 2012; Reyes-García et al., 2013). Both trait diversity and the associated knowledge are important legacies to help adapt to new conditions (Cabell and Oelofse, 2012; Reyes-García et al., 2014). In turn, access to introduced and non-farmer varieties, particularly to new climate-resilient crops and varieties, can also be an important way for farmers to cope with or adapt to climate change or other stresses (Acevedo

et al., 2020), as farmers capacity to change crop species and varieties is a common response to changing climatic conditions (Ruggieri et al., 2021; Schlingmann et al., 2021). Building up on social-ecological resilience theory (Walker et al., 2004; Cabell and Oelofse, 2012), farmers' access to crop and varietal diversity should be ensured through a repertoire of flexible responses (i.e., providing farmers with a wide range of source and crop diversity options), accounting for the trade-offs among these responses. For example, while introducing a cash-crop to the on-farm crop portfolio can work well to meet market demands and farmers' cash needs, the abandonment of drought-resistant subsistence crops can diminish agroecosystem's resilience to other stresses, like climate change (McGuire and Sperling, 2013; Porcuna-Ferrer et al., 2024a).

Conclusion

This study shows that farmers' access to seeds is conditioned by crop biocultural traits and that farmers' centrality in the seed circulation network affects on-farm crop diversity.

While our findings highlight the instrumental role of farmer-to-farmer seed circulation networks for the maintenance of local crop diversity and for the introduction of new diversity in the agricultural system, they also indicate that new seed sources, such as local markets and agricultural extension projects or NGOs, can offer access to new seeds with adaptive potential.

Considering ongoing climate change impacts in the Bassari territory, agricultural interventions need to evaluate trade-offs between responses and medium- and long- term consequences for farmers' social-ecological resilience. The challenge remains on how to enable the coexistence of new and old crops and varieties, and of modern and traditional ways of accessing seeds. In general, there is a certain consensus that horizontal, locally-adapted ways of accessing seeds (e.g., farmer-to-farmer seed circulation) are more sustainable in the long-run than top-down, hierarchical ones (e.g., agricultural extension services), but there is also growing agreement that both strategies should be reconciled for more effective crop diversity conservation (Thomas et al., 2011; Pautasso et al., 2013).

For the Bassari, reconciling both approaches would entail that agricultural extension projects and NGOs shift from the current top-down approach to multi-centric participatory approaches that situate farmers' knowledge and practices at the centre. A participatory-based approach would facilitate the broadening of projects' crop-portfolio, including traditional crops like sorghum, Bambara groundnut, and fonio. This would contribute to strengthening locally adapted crop diversity and seed systems, thereby bolstering the social-ecological resilience of smallholder farming communities in the phase of climate and global change.

Chapter 7
Conclusions

Ga-ye (time to rest)

Under the shade of a large tree, she
separates the nuts of Bambara to be used
for seed from those for kitchen needs.

She picks up a handful of nuts and shows them
to me: '*Look at them. I love the colours, these
blacks and yellows, the reds and purples'*.

Picking up a particularly large spotted seed, she
adds: '*We call this one 'onyere-nyer', it means
co-wives'*, and taking a deep breath she searches
for the right words to continue: '*You see, the
two colours clash, they both want to dominate'*.

Holding the same seed tightly, she
remarks: '*This is what makes us strong.
By eating food like this, we can work
all day long without getting tired'*.

Conclusions

Through an in-depth case-study among the Bassari, this work sheds light on the relations and processes that drive crop diversity dynamics and their implications for climate resilience. I first situated the broader context within which farmers experience climate change. I then analysed crop dynamics at the local scale to understand how climate change and agrarian transformations interact with farmers' crop choices and access to seeds.

This conclusion weaves together the different perspectives elaborated in previous chapters to present the main epistemic and methodological contributions derived thereof. I end the section by reflecting on policy implications and potential future research avenues. Although the Bassari territory of south-eastern Senegal is the primary analytical focus for this dissertation, the overarching arguments speak to broader audiences interested in halting or reversing crop diversity loss and supporting the diversification of smallholder farming systems amidst climate change.

Epistemic contributions

Through this dissertation I aimed to contribute to the literature on crop diversity dynamics and climate resilience in a context of small-scale farming. The specific findings herein contribute five original perspectives to this body of literature.

Climate change: one of many drivers shaping farmers' crop portfolios

My findings show that climate change is not the main stressor driving Bassari farmers' decisions for crop cultivation. Rather, other stressors with immediate effects play more decisive roles in explaining farmers' contemporary crop portfolios. Drivers of change in Bassari agricultural system are multifactorial, and climate change acts simultaneously and in synergy with other socio-economic, political, and cultural drivers. While Bassari farmers have a deep awareness of and are concerned about the local impacts of climate change, other factors –such as shifting gender roles, cash dependency, dietary changes, and loss of traditions– have a wider impact on local crop diversity.

This finding has two main implications. First, it underscores that a focus on climate change alone can divert attention from equally important non-climatic factors affecting smallholder farming systems. This observation stresses the importance of moving away from narratives considering climate change as the main stressor in farming systems towards considering how climate change interacts with other processes of change. In line with other political ecology works (O'Brien et al., 2007; Tschakert, 2007; Ribot, 2014; Jackson et al., 2020; Bezner Kerr et al., 2022), this insight emphasizes the need for a political understanding of climate resilience and vulnerability that accounts not only for the physical exposure to the threat, but also for the prevailing agrarian political economy and the socio-ecological conditions of farmers and communities on the ground.

The second implication of my finding refers to the importance of thinking about the short- and long-term impacts of contemporary dynamics. While climate change is not currently the main

stressor affecting Bassari farmers, the foreseeable escalation of the impacts of climate change raises concerns regarding their future significance. Assessments of the dynamics of crop diversity should therefore take the long-term implications for climate resilience into account.

Farmers' crop portfolios result from multi-actor and cross-scale interactions

My findings show that the factors shaping farmers' decisions concerning crop diversity are both individual and collective. Therefore, to reach a comprehensive understanding of crop diversity dynamics these two levels need to be considered jointly. The abandonment of traditional Bassari crops lies at the intersection between broad historical conditions, political-economic forces, and household decision-making. The causes are multifactorial and are affected by government and international policies, market integration, demographic changes, gendered contestations over agricultural labour, and access to resources.

This finding provides valuable contributions to the literature that highlights the benefits and potentialities of diversified agroecological ways of farming (Jackson et al., 2010; Altieri et al., 2015; Renard et al., 2023). While each case-study is unique, this thesis emphasizes the importance of paying attention to the feedback between global drivers of change and local-scale processes and vulnerabilities that determine farmers' choices and response options. A better understanding of the intersecting, multi-scalar, and sometimes contradictory forces that drive changes in local crop diversity can illuminate potential avenues to support diversified agroecological ways of farming and climate resilience in smallholder farming communities.

The biocultural status of crops drives their dynamics

My research shows that understanding the biocultural status that crops hold in a particular location is key to understanding crop dynamics. Literature on crop diversity has traditionally conceptualized crops as biological or as social/cultural elements. However, a growing number of studies emphasize that crop diversity results from the interplay of biophysical evolution, cultural identities, social interactions, and belief systems governing its management and structure (Nazarea, 2006b; Howard, 2010; Leclerc and Coppens d'Eeckenbrugge, 2012; Caillon et al., 2017). Drawing on previous research, I conceptualize crops as biocultural elements that emerge through a dynamic and multi-scalar network of ecological and socio-cultural interactions. This network mediates the relations between humans, their practices, and crops. I then compare the cultivation trends and the circulation of local staple crop species, accounting for their biocultural status.

My results show how crop cultivation trends and current practices of seed saving, access, and exchange depend on the biocultural status of crops. Temporal and cross-scale dynamics influenced farmers' crop choices, resulting in different cultivation trends for crops with different biocultural status. The seed circulation networks of local staple crops display diversity in terms of scale, range, and actors involved. Different rules and interactions shape the way farmers accessed seed for crops with different biocultural significance. These findings highlight the need to broaden the analytic scope of research on crops. Crop diversity research should move beyond viewing crop diversity solely in terms of genetic or species diversity to encompass the historical and cultural aspects that shape the biocultural status that crops hold in a particular location.

The contribution of social networks to diversified farming systems is a matter of biological and social diversity

The findings of this thesis show that to support the resilience of smallholder farming systems it is not enough to support the diversification of crops; it is also important to support the diversification of supply sources. This finding is in line with other research that asserts that the contribution of social networks to crop diversification depends on the diversity of the institutions and actors involved in the seed system and on the way these actors engage with each other (Labeyrie et al., 2021a).

My results show that to maintain, diversify, or adjust on-farm crop portfolios, farmers simultaneously mobilized various types of seed sources. As a result, access to crops and varieties with potentially adaptive traits is mediated by a diversity of actors. My findings also show that the ways farmers accessed seed is changing and, during this process, local seed exchange networks undergo important transformations. This observation raises the concern that centralized means of seed diffusion may displace traditional mechanisms of access to seeds.

In terms of climate resilience, my findings illustrate the importance of diversity in seed management and supply practices. The different networks of seed circulation give farmers the option to adjust their crop portfolios to ongoing socio-ecological changes. At present, however, national policies exclusively promote official channels of seed distribution, limiting farmers' access to specific crops and varieties. These crops and varieties disseminated through official lines promote intensive forms of production and do not reflect the diversity of farmers' needs. The ongoing loss of traditional crop diversity stresses the need to carefully examine the possible trade-offs and spill-over effects of current seed system dynamics on traditional practices of seed sharing and exchange.

Resilience in smallholder farming systems needs to be understood as a relational, contextual, social, and politically embedded process

The final epistemic contribution of this thesis reflects on how to make the notion of 'resilience'more relevant to smallholder farmers. This thesis presents in-depth empirical evidence on how crop diversity changes in response to environmental, social, and cultural elements across scales and time. This evidence suggests that the focus should be on the process through which resilience emerges.

My thesis started off with the quest to support more resilient ways of farming through the understanding of local crop diversity dynamics. The concept of resilience, however, has often been criticized for not challenging the status-quo and perpetuating hegemonic narratives, discourses, and interventions that neglect the social and political-economic drivers of vulnerability or 'lack' of resilience in smallholder farming systems (Cretney, 2014; Scoones, 2023). Interrogating how we (Western researchers and practitioners) frame resilience is important, as it shapes the alternatives that we can imagine, the politics of interventions, and eventually, the range of potential adaptations and responses that smallholder farmers have in the face of increased climatic and socio-economic uncertainty (Scoones, 2023). Insights from this thesis highlight that resilience needs to be understood as a relational, social, and politically embedded process. The findings show that an approach to resilience that focuses on crop diversity and climate risk alone is too narrow, and can

over-simplify the complex dynamics between crop diversity, society, and climate change. Resilience therefore needs to consider the myriad of factors impacting smallholder farming systems.

A relational approach to resilience involves situating the contemporary dynamics of crop diversity in the broader context and understanding the changes in the practices of smallholder farmers together with changing socio-ecological conditions. It also involves thinking about resilience beyond individual choices or collective dynamics and uncovering the social relations, cultural norms, power dynamics, and biophysical limits that shape farmers' decision-making. A relational approach to resilience entails shifting the focus from understanding resilience as a 'capacity' or 'property' of the system into understanding the process through which resilience emerges. Because resilience can mean very different things for different actors, even within the same community, such an approach emphasizes the need to look at the costs and trade-offs of changes for different actors and for people from different social groups. A relational approach to resilience also lays the focus on whose interests are prioritized and whose knowledge is considered legitimate.

Taking seeds as an example, framing them from a relational, contextual, socially, and politically embedded perspective entails shifting the focus from seeing them as an input or isolated element to seeing them as the embodiment of the relations that have created and maintained that seed. This includes not only the culture around it, but also relationships between women and men, generations, the state, development projects, researchers, and private companies. In this sense, supporting the pathways to resilience entails supporting all the relationships that have created and maintained the seeds while questioning all those relationships that undermine them. In the case of Bassari farmers, historical processes of exclusion and dispossession and state policies and interventions geared towards homogeneity and intensive ways of farming have constrained the possibilities for building resilience.

In summary, resilience in smallholder farming systems should not be envisaged as the state to reach. It is rather a process that emerges through farmers' everyday practice in conjunction with cross-scale dynamics, social relationships, and cultures. The state of resilience is not static. It can come and go in degrees and is experienced differently by different people. Supporting resilience entails embracing historical and ecological conditions and contemporary social and political processes. It also implies taking an inside look at power dynamics and spelling out what the politics of resilience mean for the various actors and social groups.

Methodological contributions

This thesis brings forward three important methodological contributions to the intersecting research fields of crop diversity dynamics and climate resilience.

Moving from inter-disciplinary to inter-epistemological research

This thesis uses an inter-epistemological approach to assess the interplay between crop diversity and socio-ecological dynamics under climate change. Besides combining disciplines, data sources, and theoretical traditions, my research also combines different ways of knowing. I build

on previous research that argues that Indigenous and local knowledge offers insights into the understanding of socio-ecological change that differ from those of scientific understandings. Including Indigenous and local knowledge into the generation of knowledge allows to reach situated and comprehensive understandings and move beyond disciplinary perspectives (García del Amo, 2021; Caviedes et al., 2023; Reyes-García et al., 2024a).

By collecting numerous 'clues' through multiple sources of data, such as interviews and surveys with farmers, interviews with local institutional actors, regional agricultural and weather statistics, archival research, and field inventories, my research merged Western scientific knowledge with Indigenous and local knowledge. Exploring the ways changes in crop diversity and the multiple drivers are observed and interpreted by different knowledge-holders created a nuanced picture of crop diversity dynamics without reducing its inherent complexity. It also allowed the inclusion of cultural representations of 'crops', 'climate', and 'change' in scientific framings.

While I am aware of the limitations and complexity of combining theories, types of data, and ways of knowing, I hope this methodological approach will inspire new avenues for exploring crop diversity dynamics. Inter-epistemological dialogue can deepen our understanding of the nested interactions that shape crop diversity over space and time and foster strategies for building resilience in smallholder farming systems.

Taking a relational approach to changes and drivers

This thesis uses a relational approach to changes and drivers. I explore changes in climate and crop diversity by focusing not only on the changes and drivers per se, but also on the relations between them. Using a relational approach extends contemporary work on the contributions of Indigenous and local knowledge to the understanding of socio-ecological changes by laying the focus on the interactions between changes and drivers of change (Boillat and Berkes, 2013; Reyes-García et al., 2019; Li et al., 2021). Thinking of climate and non-climate drivers of change as a network helped me identify the synergies and trade-offs between climate, environmental, socio-economic, and cultural changes. It also provided understanding of the feedback between macro- and micro-level processes driving changes in crop diversity.

Operationalizing this relational approach through network analysis allowed to visualize and quantitatively assess the importance of climate versus non-climate-related impacts and drivers. While this constitutes one step further in the study of local climate change impacts on smallholder farming systems, it should be kept in mind that the method is not specifically designed to study the impacts of environmental change. Careful interpretation of the meaning and implication of quantitative network measures is thus required.

Operationalizing the measure of crops as biocultural elements

This thesis uses the understanding of crops as biocultural elements as a conceptual tool to bridge scientific disciplines and different ways of knowing. Thinking of crops as biocultural elements entails jointly accounting for the material and immaterial, biological and cultural dimensions of crops.

In my research, I have shown the importance of considering the biological characteristics of crops, such as drought tolerance, together with socio-cultural traits, such as marketability or dietary and traditional use. I have also shown the importance of thinking of crops from a relational perspective that not only accounts for the knowledge systems and practices that shape them, but also for the network of historical trends, ecological conditions, and cultures that surround them. This involves understanding farmers' practices, such as labour distribution and decision-making, along with farmers' social connections, such as kinship or co-residency patterns. A relational perspective also entails looking across organizational levels, including the multi-actor interactions, policies, and legal codes that affect the relationship farmers have with their crops.

The way crops biocultural status has been operationalized, however, should not be seen as a ready-made tool for future data collection. Rather, it should be understood as a preliminary step to mobilize a biocultural approach to understand human-crop interactions. To improve this concept and advance an operationalization that can be further applied to advance crop diversity related research and policy, in-depth work in collaboration with researchers from other backgrounds and disciplines and with farmers and local communities is needed.

Policy implications

International and national policies regarding crop diversity and agricultural adaptation to climate change often promote top-down standardized adaptation measures that overlook farmers' local realities. Derived from my findings, I state specific avenues that can help contextualize any policy plans, projects, and interventions that aim at supporting diversified farming systems and climate resilience.

Agricultural adaptation policies should address the myriad of nested, cross-scale interactions that affect smallholder farmers

The intricate network of environmental, socio-economic, and cultural drivers affecting smallholder farming systems creates multiple trade-offs in the maintenance and broader expansion of on-farm diversified crop portfolios. Consequently, agricultural policies and interventions should not address climate change in an isolated manner but as one of many challenges facing smallholder farmers. This implies that a focus on the breeding and dissemination of new climate-adapted crops and varieties will not suffice to support diversified farming systems. For example, it is not enough to promote a new 'climate-smart variety' if the variety is not also 'culturally-smart' or 'market-smart'.

In line with other authors (Eriksen et al., 2011; Nyantakyi-Frimpong and Bezner Kerr, 2015; Ensor et al., 2019), I argue that policies to adapt agriculture to climate change should address the combined impact of the multiple stressors affecting smallholder farming systems. Policies and interventions should consider the social systems that influence ownership, exchange, and distribution of crop diversity and ensure farmers' access to key resources beyond seed, such as knowledge, land, labour, water, and finance. Without these provisions, the adoption of climate-adapted crops and varieties –and therefore farmers' resilience– will be limited.

To avoid maladaptive outcomes, the short, medium, and long-term consequences for environmental, socio-economic, and cultural dimensions need to be carefully examined and locally contextualized prior to any intervention.

Policies and agricultural interventions need to account for local vulnerabilities

My results have shown that changes in crop diversity and agricultural practices did not benefit everyone equally. In accordance with the findings of other authors (Tschakert, 2012; Bezner Kerr, 2013), my results show that the interactions between socio-economic and ecological processes at global and local scales have exacerbated negative impacts on the most vulnerable. This finding emphasizes the need for approaches to policymaking and action that consider historical conditions and examine how access and control over resources at the micro-level interact with government and international policies, affecting their implementation and outcome.

To reach policy outcomes that are more equitable and effective, it is important to conduct a thorough analysis of structural inequalities prior to any intervention. Special attention should be paid to how changes in crop diversity (or in farming practices in general) are being experienced at the household-level and across gender, class, or any other locally relevant axes of social differentiation.

Farmers' knowledge and priorities are critical for the formulation of local agricultural policy measures

Results from this thesis illustrate that including farmers' knowledge into research contributes to a better understanding of contextual entanglements between crop diversity and social and ecological realities. Mainstream research and policy, however, fail to uphold farmers' knowledge and practices and tend to underplay considerations of the local context.

In the phase of current challenges posed by climate change and societal-agricultural uncertainties, supporting on-farm crop diversity requires a move from top-down governance lines to more inclusive processes, participative actions, and shared decision-making (Méndez et al., 2013; Ibarra et al., 2023). There is no one-size-fits-all solution for adapting agricultural policies to the diversity of needs and contexts in which smallholder farmers operate. In certain contexts, or for certain individuals, diversifying on-farm crop portfolios might not be the most suitable strategy to promote resilience. In sum, supporting diversity entails embracing diversity, even if priorities and farmers' needs do not always match those of researchers and policymakers.

Farmers should be fully included in long-term government, development, and research programs

While participatory approaches to research and policy can help prioritize actions that address local needs and priorities, there is a risk that such approaches become anecdotal. Full and long-term inclusion of smallholder farmers in research and policy could be achieved by:

(i) Developing a national participatory plant-breeding program that broadens the current crop-base by including the wide range of native crops and landraces that farmers cultivate. Bringing researchers, farmers, and peasant organizations together in plant breeding and seed system development would help to prioritize locally used varieties, taking farmers' preferences and culturally-relevant traits into consideration.

(ii) Establishing a national agricultural program that supports research on agrobiodiversity -based methods and fosters long-term farmer-to-farmer experimentation and learning. Such a program would help prioritize development projects and interventions targeting crop diversity on many levels, such as through the promotion of school activities that re-valorise agriculture as a valid livelihood and native crop diversity, for example, by linking local farmers' groups with schools or by including native crop diversity into school meals. Such a program could have a platform with representatives of all local actors (i.e., farmer organizations, NGOs, the private sector, and government agencies). A platform of this type could help to better coordinate actors and research programs for more democratic decision-making.

(iii) Developing an integrated seed system at national level. This would strengthen the complementarities and links between the so-called 'formal ' and 'informal ' seed systems, providing farmers access to a diversity of crops and varieties through different channels. Such an approach would foster the shift from a seed system focused exclusively on top-down mechanisms of seed provision of productive and commercial varieties towards more plural mechanisms that also support traditional and decentralized seed access and exchange.

These approaches could help sustain diversified crop portfolios at local levels while increasing national crop diversity and resilience to shocks. Nonetheless, to be effective, these measures should be accompanied by structural changes at broader levels. There is a need to restructure agrarian policies and develop incentives to allow favourable institutional frameworks that support smallholder farmers and allow crop diversity-based farming to thrive.

Future research

Based on my findings, I present perspectives for future research that I consider will be important in order to meet the challenge of supporting diversified farming systems in the scenario of climate change.

Focusing on how all household members –not only household heads– make crop choices

Future research should engage more deeply into how different household members mobilize crop diversity in response to change. Based on my findings, I emphasize the importance of paying attention to intersectional forms of difference and power imbalances in the local communities and how these affect the way changes are experienced and faced at the household and community levels. My research, however, has only superficially explored how gender, wealth, and other axes of social differentiation intersect with the broader political-economic structures and processes affecting crop diversity dynamics.

A deeper examination into the social rules and socio-economic determinants guiding farmers' access to and adoption of crop diversity will fill the gaps of empirical evidence regarding the reasons for adopting or abandoning crops and varieties (Acevedo et al., 2020). In the field of seed network analysis, it could be especially promising to take an intersectional look at intra-household power dynamics together with the rules guiding how seeds are accessed, who holds control over them, and how they are selected and distributed. Such an in-depth approach will not only contribute to a better understanding of patterns of seed access and exclusion, it will also help adapt the current channels and mechanisms of seed provision to farmers' individual needs and constraints.

Shifting focus: from mainstream major crops to neglected and underutilized crops, and from singular crops to diversified crop baskets

More efforts should be invested in advancing research on neglected and underutilized crop species (NUS) and landraces. NUS may play an important role in supporting the diversification of smallholder farming systems, especially under climate change conditions (Chivenge et al., 2015; Mabhaudhi et al., 2019). My findings highlight the potential of Bassari traditional crops to address both socio-economic and climate challenges. However, although these crops are well-adapted to harsh environmental conditions and provide nutritional diversity, their cultivation is decreasing due to constraints such as low yields, a lack of short-cycle varieties, high work demands, and limited marketability. Research has suggested that many of the lock-ins that hinder the cultivation of NUS could be overcome with more research and greater formal support (Stamp et al., 2012; Hunter et al., 2019; Ulian et al., 2020; Kaczmarek et al., 2023). For example, more resources and attention to their breeding potential and varietal development, as well as to their seed systems, management, utilisation, and marketing could help realise the untapped potential of NUS and foster their wider use.

Another promising research line to support smallholder farmers cope with the risks related to climate change while also addressing their market and cultural needs consists of moving beyond thinking of individual crop species to thinking in terms of crop baskets. NUS might be more stress-tolerant than most major crops. However, a climate adaptation strategy based only on the promotion of NUS would not cover all the other needs of smallholder farmers. Future research should explore which combination of NUS and major crops and varieties best satisfies farmers' plural needs while also optimizing climate resilience across scales.

Meaningfully engaging with inter-epistemological dialogue

Finally, in line with findings from a growing number of works (Leff, 2002; Escobar, 2014; Reyes-Tengö et al., 2014; García et al., 2019), my conclusions support the need for in-depth research and discussions on how to enable a meaningful dialogue between disciplinary backgrounds and different ways of knowing. I have argued in this thesis that addressing climatic and socio-economic challenges and better supporting crop diversity in smallholder farming systems requires the joint effort of scientists, farmers, and policymakers. However, it remains to be answered how scientists can best collaborate with local farmers and stakeholders to ensure the robustness and relevance of the findings and effectively enhance the resilience of smallholder farming systems.

The prioritization of participatory approaches and knowledge co-production raises questions and concerns related to epistemological and ontological power asymmetries and ethical aspects related to full consultation and intellectual property rights (Nadasdy, 1999; Goldman et al., 2018; Orlove et al., 2023). Future research should explore what type of institutional arrangements and frameworks could best overcome these challenges, prioritizing bottom-up inter-epistemological research that does not favour one knowledge system over the others.

Future lines of work in the field of crop diversity should aim to formulate research protocols and guidelines that ensure that farmers and local communities have more control over the research process, enabling more horizontal, just, and meaningful partnerships. For example, more impact-oriented research could be achieved by including farmers in the framing of breeding objectives, variety evaluations, and assessments of seed system interventions. Farmers should also be included in all stages of the design of climate change adaptation plans and agricultural policy programs. This will not only help in the implementation, but will also give more legitimacy to the process.

For such approaches to thrive, there is a need to challenge dominant academic structures and success metrics that do not support inter-epistemological research (Sundberg, 2014; Todd, 2016; Liboiron, 2021). It is time to devise a slower, more conscious and more caring academia that includes and builds on feminist and decolonial perspectives (Manzi et al., 2019; Iniesta-Arandia et al., 2020). This will entail collectively exploring new ways to encourage collaborative work and community-engaged methods that match the concerns of farmers and local communities, as well as those of researchers and policymakers.

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Appendices

Appendix 1

List of other scientific publications and communications

Throughout my doctoral journey, alongside the four empirical chapters comprising this dissertation, I have also contributed to the following peer-reviewed publications, book chapters and dissemination materials:

Peer-reviewed publications

Reyes-García, V., García-del-Amo, D., Benyei, P., Fernández-Llamazares, Á., Gravani, K., Junqueira, A. B., Labeyrie, V., Li, X., Matias, D. M. S., McAlvay, A., Graham Mortyn, P., **Porcuna-Ferrer, A.**, Schlingmann, A., Solymani-Fard, R., 2019. A collaborative approach to bring insights from local observations of climate change impacts into global climate change research. *Current Opinion in Environmental Sustainability*, 39, 1-8. https://doi.org/10.1016/j.cosust.2019.04.007

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Labeyrie, V., Renard, D., Aumeeruddy-Thomas, Y., Benyei, P., Caillon, S., Calvet-Mir, L., Phanie, S., Re, M., Demongeot, M., Descamps, E., Junqueira, A., Li, X., Locqueville, J., Mattalia, G., Miñarro, S., Morel, A., **Porcuna-Ferrer, A.**, Schlingmann, A., Vieira, J., Carrière, S., 2021. The role of crop diversity in climate change adaptation: insights from local observations to inform decision making in agriculture. *Current Opinion in Environmental Sustainability,* 15-23. https://doi.org/10.1016/j.cosust.2021.01.006

Ruggieri, F., **Porcuna-Ferrer, A.**, Gaudin, A., Faye, N. F, Reyes-García, V., Labeyrie, V., 2021. Crop Diversity Management: Sereer Smallholders' Response to Climatic Variability in Senegal. *Journal of Ethnobiol*ogy, 41(3), 389-408. https://doi.org/10.2993/0278-0771-41.3.389

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Reyes-García, V., García-del-Amo, D., **Porcuna-Ferrer, A.**, Schlingmann, A., Abazeri, M., Attoh, E. M. N. A. N., Ávila, J. V. C., Ayanlade, A., Babai, D., Benyei, P., Calvet-Mir, L., Carmona, R., Caviedes, J., Chah, J., Chakauya, R., Cuní-Sanchez, A., Fernández-Llamazares, A., Galappaththi, E.K., Gerkey, D., Graham, S., Guillerminet, T., Huanca, T., Ibarra, J. T., Junquiera, A. B., Li, X., López-Maldonado, Y., Mattalia, J., Samakov, A., Schunko, C., Seidler, R., Sharakhmatova, V., Singh, P., Tofighi-Niaki, A., Torrents-Ticó, M., LICCI Consortium, 2024. Local studies provide a global perspective of the impacts of climate change on Indigenous Peoples and local communities. *Sustainable Earth Reviews*, 7, 1. https://doi.org/10.1186/s42055-023-00063-6

Reyes-García, V., García-Del-Amo, D., Álvarez-Fernández, S., Benyei, P., Calvet-Mir, L., Junqueira, A. B., Labeyrie, V., Li, X., Miñarro, S., Porcher, V., **Porcuna-Ferrer, A.**, Schlingmann, A., Schunko, C., Soleymani, R., Tofighi-Niaki, A., Abazeri, M., Attoh, E. M. N. A. N., Ayanlade, A., Avila, J. V. C., Babai, D., Bulamah, R. C., Campos-Silva, J., Carmona, R., Caviedes, J., Chakauya, R., Chambon, M., Chen, C., Chengula, F., Conde, E., Cuní-Sanchez, A., Demichelis, C., Dudina, E., Fernández-Llamazares, A., Galappaththi, E. K., Geffner-Fuenmayor, C., Gerkey, D., Glauser, M., Hirsch, E., Huanca, T., Ibarra, J. T, Iquierdo, A., Junsberg, L., Lanker, M., López-Maldonado, Y., Mariel, J., Mattalia, G., Miara, M. D., Torrents-Ticó, M., Salimi, M., Samakov, A., Seidler, R., Sharakhmatova, V., Shrestha, U. B., Sharma, A., Singh, P., Ulambayar, T., Wu, R., Zakari, I. S., 2024. Indigenous Peoples and local communities report ongoing and widespread climate change impacts on local social-ecological systems. *Communications Earth and Environment*, 5, 29. https://doi.org/10.1038/s43247-023-01164-y

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Book Chapters

Ellssel, P., **Porcuna Ferrer, A.**, Freyer, B., 2022. Developing a collaborative Master's curriculum and innovative learning and teaching tools for sustainable agricultural development. In: *APPEAR II - New pathways towards participative knowledge production through transnational and transcultural academic cooperation*. Studienverlag Innsbruck & Wien.

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Other publications

Labeyrie, V., Renard, D., Benyei, P., Braga Junqueira, A., Li, X., Porcher, V., **Porcuna-Ferrer, A.**, Schlingmann, A., Soleymani-Fard, R., Reyes-García, V., 2020. *Protocol for the Collection of Cross-cultural Comparative Data on Local Indicators of Climate Change Impacts on Crop Diversity Trends*. Figshare. https://doi.org/10.6084/m9.figshare.17142350.v1

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Participation in conferences and workshops

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Reyes-García, V., da Cunha Ávila, J. V., Laura Calvet-Mir, L., Caviedes, J., **Porcuna-Ferrer, A.**, 2023. Indigenous Peoples and local communities, climate change, and local food systems. *VIII Wallace Conference, Transforming Food Systems in Latin America and the Caribbean*.

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Schunko, C., Cruz-Gispert, A., Alvarez-Fernandez S., García-del-Amo, D., Klappoth B., Lesi F., Porcher, V., **Porcuna-Ferrer A.**, Junqueira A., Li, X., Reyes-García, V., 2023. Lokale Gemeinschaften beobachten vielfältige Veränderungen von Biodiversität. *Tage der Biodiversitäts, Gemeinsam auf dem Weg aus der Biodiversitätskrise*, *Wien, 8-10 November 2023*.

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Reyes-García, V., Corbera, E., **LASEG group**, 2021. Climate Change Impacts on the Mediterranean Basin: A Social-Ecological Perspective. In: *Socioeconomic impacts of climate change*. Link

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Reyes-García, V., Nunes, C., Vidal-González, P., Benyei, P., Blanch, J., Calvet-Mir, L., Junqueira, A., **Porcuna-Ferrer, A.**, 2022. *The weather is in disarray. Climate perception of a generation*. L'Etno-Museu Valencià d'Etnologia, Exhibition. Link

Porcuna-Ferrer A., Klappoth B., Guillerminet T., 2023. Agrobiodiversity in transition: indigenous crop trajectories and climate change adaptation in south-eastern Senegal. Results from the LICCI project. https://doi.org/10.13140/RG.2.2.30411.77607

Video: *Speaker in dissemination video of first results from the LICCI project*. Video

Video: *Session speaker in LICCI online training workshop on "crop diversity"*. Video

Video: *Presentation "Do Community Seed Banks contribute to social-ecological resilience?"* selected for 6th BOKU sustainability day at University of Natural Resources and Life Sciences, Vienna. Video

Appendix 2

Table 1s: Classification and coding of the observations of environmental change and respective drivers reported by the Bassari in the semi-structured interviews with consensus in the focus group discussions. Numeric values correspond to the proportions of times a driver system was cited for a given change: A, Atmospheric; P, Physical; B, Biological; S, Socioeconomic.

System		Drivers (in %)			
Subsystem	**Changes**	**A**	**P**	**B**	**S**
Atmospheric system					
Temperature	In mean temperature (not further specified)	0	50	50	0
Precipitation	In the amount of rainfall in a given season	0	16.6	33.3	50
	In the length/duration of dry spells	0	0	0	100
	In the predictability of rainfall	50	0	50	0
	In fog thickness/density	50	50	0	0
	In the frequency of fog or misty days	50	50	0	0
	In the length/duration of fog	50	50	0	0
	In air moisture/humidity	100	0	0	0
Air masses	In wind strength or speed	0	0	50	50
	In wind temperature	50	50	0	0
Physical system					
Continental waters	In freshwater availability	0	22.2	44.4	33.3
	In freshwater quality (not further specified)	0	100	0	0
	In the phreatic level	100	0	0	0
	In abundance of rivers or streams	33.3	0	33.3	33.3
	In river/stream water flow, volume, level and/or depth	100	0	0	0
	In the timing of seasonal fluctuation in river/stream/lake water level	20	0	60	20
	In the number of natural freshwater springs	33.3	66.6	0	0
	In the intensity of river/lake floods	100	0	0	0
	In the speed of aquifer recharge	100	0	0	0
Soil and land	In soil fertility	33.3	0	0	66.6
	In soil moisture/humidity	66.6	0	33.3	0
	In soil temperature	0	50	50	0
	In soil water infiltration	50	0	50	0
	In rain-induced soil erosion and soil loss	50	0	0	50
	In wind-induced soil erosion and soil loss	50	0	0	50
	In wildfire frequency	20	0	0	80

System		Drivers (in %)			
Subsystem	**Changes**	**A**	**P**	**B**	**S**
Biological system					
Freshwater fauna	In the abundance of freshwater animal species, excluding fish (mammals, birds, amphibians, reptiles, crustaceans, etc)	0	66.6	0	33.3
	In the abundance of freshwater fish	0	100	0	0
Terrestrial wild fauna	In the abundance of terrestrial fauna (mammals, birds, reptiles, insects, etc)	0	0	28.57	71.42
Terrestrial wild flora	In the abundance or density of wild plant or fungi species	0	40	20	40
	In the distribution of wild plant or fungi species	16.6	16.6	0	66.6
	In the regeneration of wild plant species	0	50	0	50
	In wild plant or fungi species mortality	66.6	0	0	33.3
	In the productivity of wild plant or fungi species (without further specification)	55.5	11.1	0	33.3
Socio-economic system					
Livestock	In the frequency of livestock disease	25	0	25	50
	In livestock behaviour	33.3	0	33.3	33.3
Cultivated plant spp.	In crop maturation time	100	0	0	0
	In crop mortality rates	83.3	66.6	0	0
	In crop productivity/yield	62.5	12.5	25	0
	In the frequency of crop pests (insects, birds, larvae, etc)	0	0	0	100
	In the frequency of successful cropping seasons	100	0	0	0
	In length of cropping season (not further specified)	100	0	0	0
Pastures and grasslands	In pasture cover, surface or abundance	33.3	33.3	0	33.3
	In the species composition of pastures	0	0	66.6	33.3
Human health	In the frequency of conflicts over natural resources	0	33.3	33.3	33.3
	In the incidence of human diseases (flu, allergies, etc)	0	33.3	0	66.6
	In the incidence of human waterborne diseases	0	100	0	0
	In the shelf life of food products	0	0	100	0
Infrastructure	In frequency of problems with transportation	33.3	33.3	0	0
Values	In cultural identity/spiritual values	0	0	100	0
Other drivers	Land-use change	0	0	0	100
	Pollution	0	0	0	100
	Resource extraction	0	0	0	100
	Technological	0	0	0	100

Appendix 3

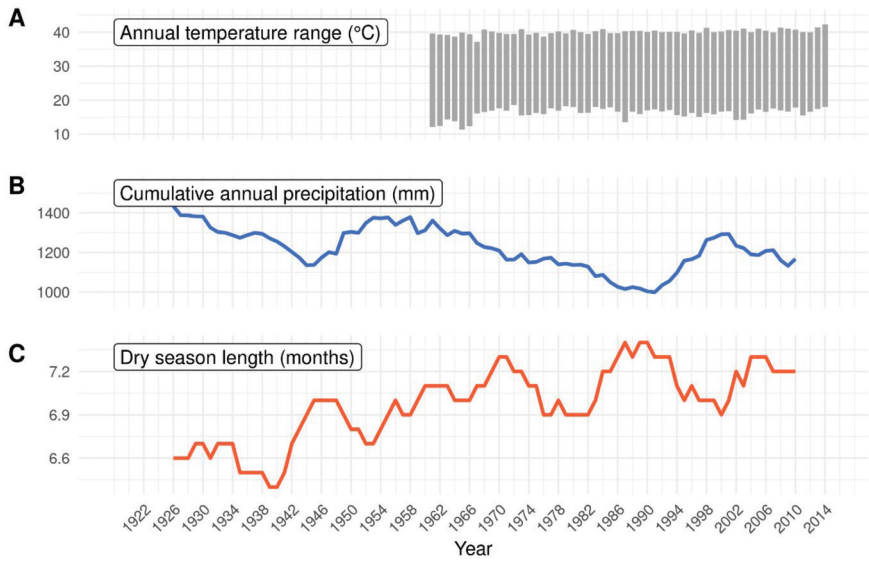

Figure 1s: Climate trends in the region of Kédougou from 1922 to 2015. A) Annual range of temperature (1961 to 2015) in degrees Celsius represented by grey vertical lines. B) The cumulative annual precipitation represented in blue as a moving average computed on a time window of 10 years. C) Dry season length expressed as the number of months in the year that had < 60 mm of precipitation, represented in red as a moving average computed on a time window of 10 years too. Data source: ANACIM (2020).

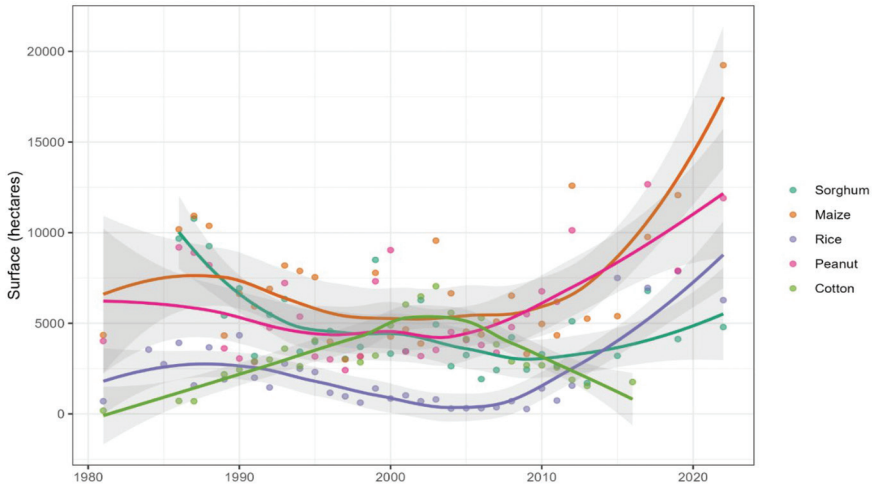

Figure 2s: Evolution of the area cultivated (in ha) with each crop in the Kédougou region between 1980 and 2022. Trend line calculated using the geom_smooth function with the loess method, R package ggplot 2. Data source: ANSD (2023).

Table 1s: Crop cultivation in 2019 (total number and percentage of households per crop) and reported trends (total number and percentage of households per crop). Data obtained through household surveys (n = 49).

Crop	Total number of households	% of households	Trend	Total number of households	% of households
Sorghum	29	59.2	Reduction of cultivated surface	10	20.4
			Increase of cultivated surface	1	2.0
			Abandonmnent	16	32.7
			Adoption	1	2.0
Bambara groundnut	25	51.02	Reduction of cultivated surface	17	34.7
			Increase of cultivated surface	0	0.0
			Abandonmnent	13	26.5
			Adoption	0	0.0
Fonio	18	36.7	Reduction of cultivated surface	2	4.1
			Increase of cultivated surface	0	0.0
			Abandonmnent	20	40.8
			Adoption	4	8.2
Maize	49	100	Reduction of cultivated surface	4	8.2
			Increase of cultivated surface	9	18.4
			Abandonmnent	0	0.0
			Adoption	19	38.8
Rice	43	87.8	Reduction of cultivated surface	5	10.2
			Increase of cultivated surface	3	6.1
			Abandonmnent	2	4.1
			Adoption	17	34.7
Peanut	49	100	Reduction of cultivated surface	5	10.2
			Increase of cultivated surface	7	14.3
			Abandonmnent	0	0.0
			Adoption	5	10.2

Appendix 4

Table 1s: Definitions and summary statistics of variables used in the generalized linear models for the seed circulation networks, by crops. Sample sizes: sorghum (n = 79 households), Bambara groundnut (n = 98), fonio (n = 50), maize (n = 114), rice (n = 102), peanut (n = 116).

		Mean (min-max)					
Variable	**Description**	**Sorghum**	**Bambara groundnut**	**Fonio**	**Maize**	**Rice**	**Peanut**
I. Outcome variable							
All varieties	Total number of varieties cultivated by the household	1.33 (1-3)	1.32 (1-3)	1.05 (1-2)	1.58 (1-4)	1.34 (1-3)	2.53 (1-6)
Farmer varieties	Number of farmers' varieties cultivated by the household	1.30 (1-3)	0.95 (0-2)	0.87 (0-1)	0.2 (0-1)	0.01 (0-1)	0.94 (0-3)
Introduced farmer varieties	Number of introduced farmers' varieties cultivated by the household	0.027 (0-1)	0.37 (0-1)	0.17 (0-1)	0.93 (0-3)	0.76 (0-2)	1.53 (0-4)
Non-farmer varieties	Number of non-farmers' varieties cultivated by the household	-	-	-	0.45 (0-2)	0.58 (0-2)	0.06 (0-1)
II. Explanatory variables							
Indegree	Number of transactions in which the household received seeds	1.62 (0-4)	2.11 (0-7)	1.42 (1-3)	1.89 (0-7)	1.86 (1-6)	3.65 (1-13)
From projects	Number of transactions in which the household received seed from projects	0.014 (0-1)	-	0.02 (0-1)	0.37 (0-3)	0.62 (0-4)	0.052 (0-1)
From market vendors	Number of transactions in which the household received seed from outside the case-study village	-	-	-	0.01 (0-1)	0.01 (0-1)	0.14 (0-2)
From households within the case-study village	Number of transactions in which the household received seed from other households within the case-study village	1.38 (0-4)	1.23 (0-5)	1.22 (0-3)	1.55 (0-5)	1.49 (0-5)	2.870 (0-12)
From households outside the case-study village	Number of transactions in which the household received seed from households from outside the case-study village	0.22 (0-1)	0.87 (0-4)	0.2 (0-2)	0.28 (0-2)	0.05 (0-1)	0.64 (0-4)

Variable	Description	Mean (min-max)					
		Sorghum	Bambara groundnut	Fonio	Maize	Rice	Peanut
Outdegree	Number of transactions in which the household was mentioned as seed giver	1.01 (0-6)	0.98 (0-12)	0.77 (0-5)	1.13 (0-14)	1.07 (0-11)	2.33 (0-24)
Betweenness	Number of times a household is at the shortest path in transactions between two other households. The shortest path is calculated based on the number of nodes that separates the households	3.71 (0-48)	14.39 (0-229)	2.12 (0-19)	8.47 (0-113)	7.38 (0-76)	473.13 (0-3880)
III. Control variables							
Adults in the household	Total number of adults (> 18 y) living in the household	4.33 (1-11)	4.15 (1-11)	4.62 (1-11)	4.17 (1-11)	4.38 (1-11)	4.15 (1-11)
Women in the household	Percentage of the total adults in the household who are females	57.88 (25-100)	58.60 (25-100)	58.91 (25-100)	58.39 (25-100)	57.6 (25-100)	58.75 (25-100)
Age group of the household head	Age group of male household head, or female when men were absent (n = 13, 11.1%):						
	Group 1: 0-19 years old	0%	0%	0%	0%	0%	0%
	Group 2: 20-29 y	4.11%	8.51%	10%	7.83%	9.09%	7.76%
	Group 3: 30-45 y	45.21%	42.55%	40%	43.48%	46.46%	43.97%
	Group 4: 46-60 y	32.88%	28.72%	32.50%	30.43%	31.31%	30.17%
	Group 5: > 60 y	17.81%	20.21%	17.50%	18.26%	13.13%	18.10%
Surface cultivated	Total surface cultivated by the household for a specific crop as approximated by the farmers. In cordes (local unit, 1 corde = 0.25 ha)	0.99 (0-4)	0.51 (0-1.75)	1.09 (0.25-2.5)	1.84 (0.15-10)	1.54 (0.5-4.5)	2.14 (0-10)
Economic status of the household	Variable that approximates the economic status of households. Based on local conceptions of wealth, household economic status was divided into three categories: low, medium, and high. Household inclusion in these categories was determined by the possession of ten material items with market value (e.g., solar panel, motorbike, oxen plough):						
	Group 1: low	42.47%	40.43%	30.00%	40.00%	36.36%	40.52%
	Group 2: medium	45.21%	44.68%	60.00%	45.22%	47.47%	44.83%
	Group 3: high	12.33%	14.89%	10.00%	14.78%	16.16%	14.66%

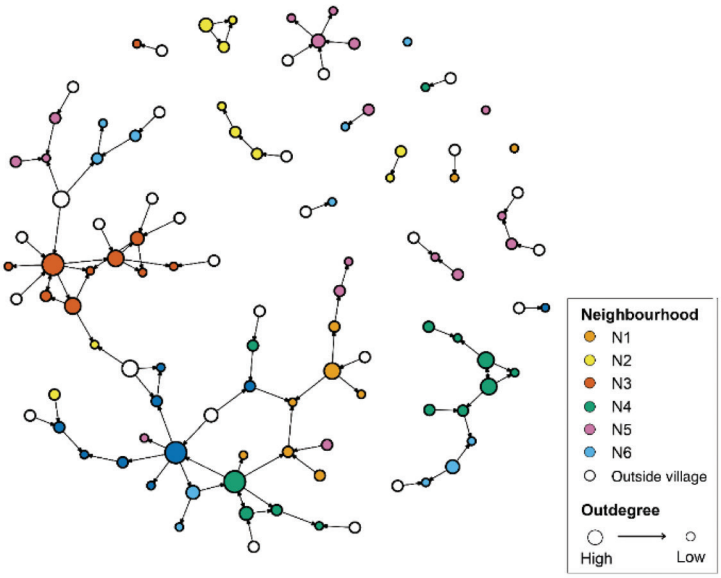

Figure 1s: Sorghum seed circulation network according to neighbourhood.

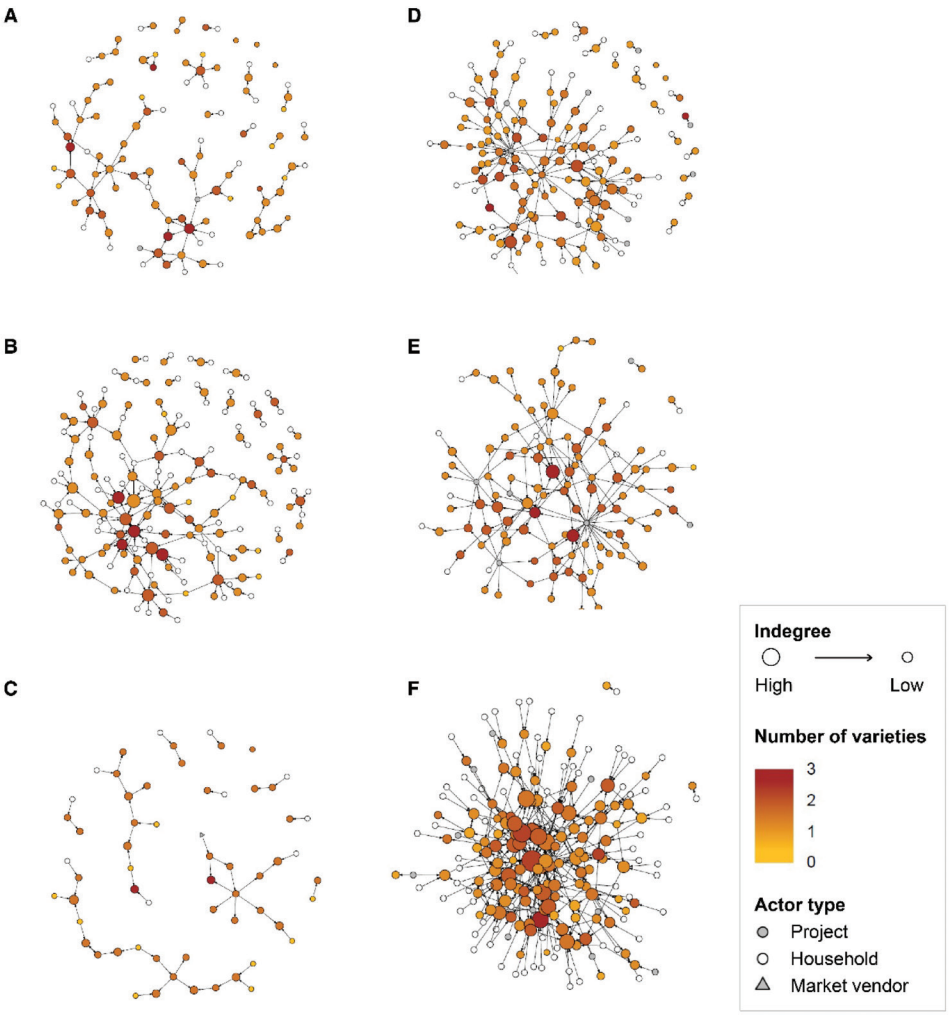

Figure 2s: Number of varieties cultivated in relation with household's indegree, per crop. A) Sorghum, B) Bambara groundnut, C) fonio, D) maize, E) rice, F) peanut.